EFFICIENT USE OF FERTILIZERS

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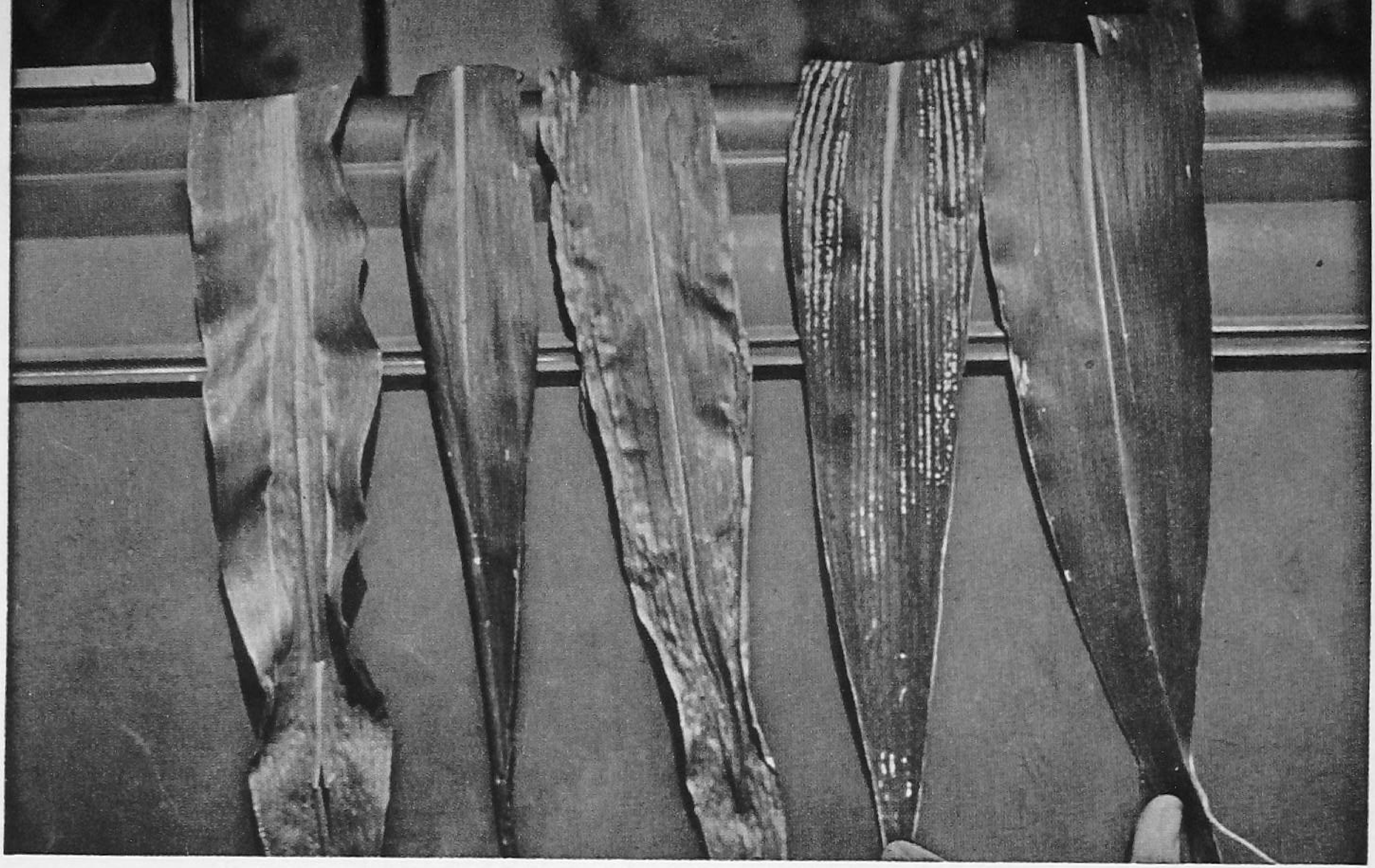

Maize deficient in NITROGEN. PHOSPHORUS. POTASH. MAGNESIUM. WELL FED.

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EFFICIENT USE OF FERTILIZERS

EDITED BY

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I

THE ROLE OF FERTILIZERS

A hungry world needs food. If the soils, the people, and the skills of modern science can be brought into proper relationship, an efficient agriculture can supply the food. One can see how enormous the task is and still assert that it is manageable.

The efficient use of manures and fertilizers is one of the most important technical factors in food production. This monograph deals with the subject especially for agricultural administrators and advisers who work with farmers and farm organizations. It is not an exhaustive treatise for technicians. Nor is it a detailed handbook of complete recommendations for particular local areas. Rather, it has a different purpose from either of these—the purpose of helping agricultural administrators and advisers all over the world to spread the available knowledge about fertilizers and their use for crop production. The more significant relations of fertilizers to crop rotation, erosion control, irrigation, drainage, liming, and other practices are dealt with briefly. An attempt is made to present the basic principles simply, as men of experience view them. But what is said here needs to be supplemented by local research and experience in order to make these principles more specific and their application to local soil types and cropping systems more precise.

Nearly everywhere that efforts are made to raise agricultural efficiency and increase food production for an expanding population, more fertilizers and animal manures are needed. The great potentialities for sustained production increases through the increased use of fertilizers were convincingly demonstrated during the war years by experience in Canada, India,[1] the United Kingdom, and the United States.

Fertilizers and manures enable farmers to increase production and get higher returns for their expenditure of work and materials. Perhaps even more important, on many soils they make possible good yields of valuable crops that would not grow at all without them, or would grow very poorly.

Primarily, fertilizers and manures are used to increase the supply of plant nutrients already in the soil. Although every essential nutrient

[1] References to India throughout this study are intended to be geographical, and refer also to Pakistan where applicable.

is added, singly or in a fertilizer mixture with others, in practical farming somewhere in the world, only a few are used widely on many soils. Phosphorus, potassium, and nitrogen are most generally needed. Calcium and magnesium are used in fertilizers, but even more widely in liming materials. Sulphur and boron are deficient in some places, and any of the other nutrient elements—iron, manganese, copper, zinc, and molybdenum—may be required on some soils.

Crop growth depends, however, upon a whole set of conditions in addition to the nutrient supply. The more important influencing factors include:

(1) *Temperature of air and soil.* Near the lower and upper limits for plant growth, and near the frost point, local site selection is critical. Small but significant changes in temperature can be made with mulches, cover crops, and tillage practices.

(2) *Light, including varying lengths of day.* Light is essential to all green plants because it provides energy for food manufacture and storage. But too high intensity of sunlight retards certain life processes, especially in shade-loving species. Shade can be used to lower the intensity of light.

(3) *Soil depth and structure.* Roots need a good foothold. Often soil structure can be greatly modified, even to considerable depth, to give them this foothold.

(4) *Soil moisture.* The amount of moisture in the soil varies with climate, slope, soil structure, and plant cover. It can be changed by irrigation, drainage, runoff control, tillage, and weed control.

(5) *Soil air.* Plant roots need air. The supply can be greatly modified by drainage and somewhat modified by tillage.

(6) *Soil slope and stoniness.* These factors influence water control and the use of machinery.

(7) *Excess salts.* On many soils excess salts can be removed and their accumulation prevented by drainage, leaching, and other practices.

(8) *Plant diseases and insects.* The use of disease-resistant varieties, seed treatments, appropriate sprays to prevent plant diseases, and suitable insecticides are the chief control measures.

(9) *Hazards of floods and violent winds.* Protective levees and windbreaks are often practicable.

In those places where low nutrient supply is the only unfavourable condition fertilizers give an enormous return. But fertilizers cannot help to overcome other handicaps, except to a small degree. The effectiveness of manures and fertilizers depends upon selecting land

with suitable conditions, selecting adapted plants, and perhaps correcting one or more other conditions at the time the fertilizer is used.

The successful farmer brings about a good fit between his crops and his land, partly by selecting adapted crops and crop varieties and partly by changing the character of his land through management. In some places, only a little needs to be done to bring about a great change in the crop potential. On many soils in humid regions, for example, the use of lime and fertilizer makes possible large yields of legume hay, which could not be grown at all without these materials. In turn, the legumes improve the soil for other crops and furnish feed for livestock. The fertilizer thus makes more effective all the other growth factors and the farmer's labour. Such soils are said to be highly responsive to management; that is, their productivity can be increased far above the natural level. Other soils respond to fertilizers only after drainage or irrigation. Many soils give excellent yields only when a whole set of complicated practices is well fitted together.

The particular combinations of growth factors most favourable for individual kinds of crop plants vary widely. The world offers a vast complexity of soils and growing conditions to which economic plants are differently adapted. Although this accounts for much of the interesting variety in the world, it greatly complicates the problem of effective fertilizer use.

The main point is that fertilizers, manures, and soil amendments can make an effective contribution to production only when all factors are in reasonable balance for an adapted crop or combination of crops and when the needed nutrients are applied in proper amounts. Otherwise, they are wasted or only partly effective. Thus the adviser needs to consider many factors before recommending a fertilizer practice on a particular farm.

Fertilizers in the Farming System

Most crop production takes place on fairly small units of operation. These vary from small general farms operated by a single family and producing a wide variety of field crops, fruits, vegetables, and livestock products, to large plantations concentrating on a single industrial crop. Decisions about practices are made *within* these units. This complicates the problem of the agricultural administrator or adviser, since recommendations must be specific both for local soil conditions and for the management systems of individual units.

The farming system may be very simple or exceedingly complex, depending upon the economy of the community, the potentialities of the soils, and the skill and resources of the operator.

Consciously or unconsciously, each farmer has a plan. It may be based mainly on tradition and thought out only a season in advance; or it may be carefully written down long ahead and revised from year to year. Nothing is more important to the effective use of fertilizers than advance planning. Many of the best practices are most effective only over a period of years. Where all the emphasis is on the next season's crop, farmers commonly fail to adopt practices that build up their soils to a high state of productivity and keep them there.

Just as several factors in correct combination are necessary for plant growth, so also the parts of a farming system must fit together for the whole to succeed. The parts need individual attention, but each part influences the others. The application of manures and fertilizers is one part, a part which may be of little help if any other part is unsatisfactory for good production. The factors which make for successful farming and the efficient use of fertilizers and manures may be briefly described.

(1) There should be a satisfactory balance among the major land uses—for example, forestry, grazing, and crop production—according to the pattern of soil conditions on the farm and the need for balance among enterprises. When livestock is produced, there must be a proper balance between range or pasture and feed crops. On a plantation, balance is needed between industrial crops and food crops.

(2) There should be a well-planned cropping system. Although in a few situations the same crop may be grown year after year in monoculture, the greatest efficiency generally results from growing crops in sequences or rotations, including some meadows with deeply-rooted legumes, or in mixed cultures of two or more plants together. Good seed of those varieties having the greatest disease resistance, drought tolerance, and yield and quality for the local soil types should be used.

(3) Tillage methods should result in preparing seedbeds properly and on time, making the soil receptive to water, incorporating organic matter, lime, and fertilizer deeply in the soil where necessary, and controlling weeds. In regions of high winds the ground must be left cloddy and rough, with stubble at the surface to prevent soil blowing.

(4) Crops and livestock should be given the necessary protection against winds, insects, rodents, diseases, and other hazards.

(5) There should be a system of orderly water use and disposal. Some farms have naturally well-drained soils and dependable rainfall. Many do not. Excess runoff of rain water must be prevented through close-growing plant cover, strip-cropping or terracing, or in other ways, so that the water will stay in the soil for plant growth and not

be lost or cause erosion. In regions having heavy showers and erosive soils, the management plan must provide for runoff control, else all other practices may come to nothing because of erosion. Wet soils need drainage for most crops. Lowlands need protection from flood waters. Dry soils need irrigation. Although extensive irrigation and drainage usually require large community works, the farmer can often do much by his own effort if he recognizes the need. Generally, the aim should be to save water for crops but dispose of the excess promptly in ways that will not cause damage.

(6) A system for the conservation and use of organic matter is necessary. Optimum use needs to be made of animal manures and crop residues, losses of which, through fire, leaching, and neglect, are enormous. Where fertilizers and manures are scarce or expensive, composts are especially important. Part of the need for soil organic matter can be met in the cropping system itself by planning for grass-legume meadows, deeply rooted legumes, green-manure crops, and cover crops. On many soils, especially in the tropics, legume cover crops and mulches are needed.

(7) On acid soils, liming is necessary to permit growth of the deeply rooted legumes and many other valuable crops and to create soil conditions favourable for other plant nutrients. On such soils, this is almost the first essential for an effective cropping system.

(8) A system of fertilizer use needs to be developed with the other practices to make possible the best combination of crops and to assure high yields. The system must take account of all the crops in the rotation or mixed culture and the manure supplies, among other things. The effects are interacting, as may be illustrated by the following examples:

A farmer is getting low yields of grain on a sloping soil where much of the rain water runs off. Plants are widely spaced. He acts to control the runoff and thus to increase the moisture supply in the soil. His crop yields, however, remain about the same because of the low nutrient supply. But, with the soil more moist, he now adds fertilizer and spaces the plants a little closer. The same land then produces markedly higher yields. No one practice by itself was effective, but a combination of intelligently applied practices brought results.

A farmer is growing intertilled crops on soils too acid and too low in mineral nutrients for lucerne (alfalfa) or other deep-rooted legumes. The intertilled crops require fertilizers that are relatively high in nitrogen. Instead of purchasing the nitrogen, the farmer decides to grow a leguminous crop in the rotation to enrich his soil with nitrogen from the air. He applies lime and phosphate and

potassium fertilizers to the land, sufficient for a good crop of lucerne. This crop furnishes the soil with a large part of the nitrogen needed for the intertilled crops. The expense of buying nitrogen fertilizer has been avoided, the acidity of the soil has been lessened by liming, the soil has acquired better tilth, and a better crop-to-land relationship has been established.

Kinds of Fertilizers and Manures

A large number of materials can be used as fertilizer. They vary in effectiveness on different kinds of soil and for different crops. Some may be obtained locally; others need to be shipped long distances. Although the concentrated sorts, very rich in one or more plant nutrients, may be more expensive at the point of manufacture than those of low analysis, they are usually cheaper when distance is considered. A large part of the cost of a chemical fertilizer *on the farm* is the cost of transportation. Farmers far from the source of supply should learn to order the most concentrated kinds for greatest economy in shipping. The concentrates may then be mixed with local materials on the farm or in a community plant.

The agricultural adviser on fertilizer use needs to weigh the relative advantage of different materials against their relative availability and cost.

Sustained Production Goals

The aim of agriculture must be sustained production—production and conservation together. But on both these levels, we are now failing to achieve this aim. The world is short of food and many soils are deteriorating. Some soils are declining in fertility and organic matter. Some are losing their granulation and becoming hard and massive or loose and powdery. Erosion is still taking a heavy toll. All these effects are inter-related. Loss of fertility leads to weakened plant growth. This means that the soil has a less effective cover. Then erosion removes the granular surface soil, exposing massive soil that is difficult to get into good tilth (see photo No. 1).

Erosive soil on slopes needs a protective cover that is also a productive cover, and fertilizers make it possible to establish such a cover. On the non-erosive soils, fertilizers enable the farmer to increase his yield of row crops, such as maize and cotton (see photo No. 2). But to get these results of good land use, the farmer must be able to plan ahead, to see his production over a period of years, not simply for one season.

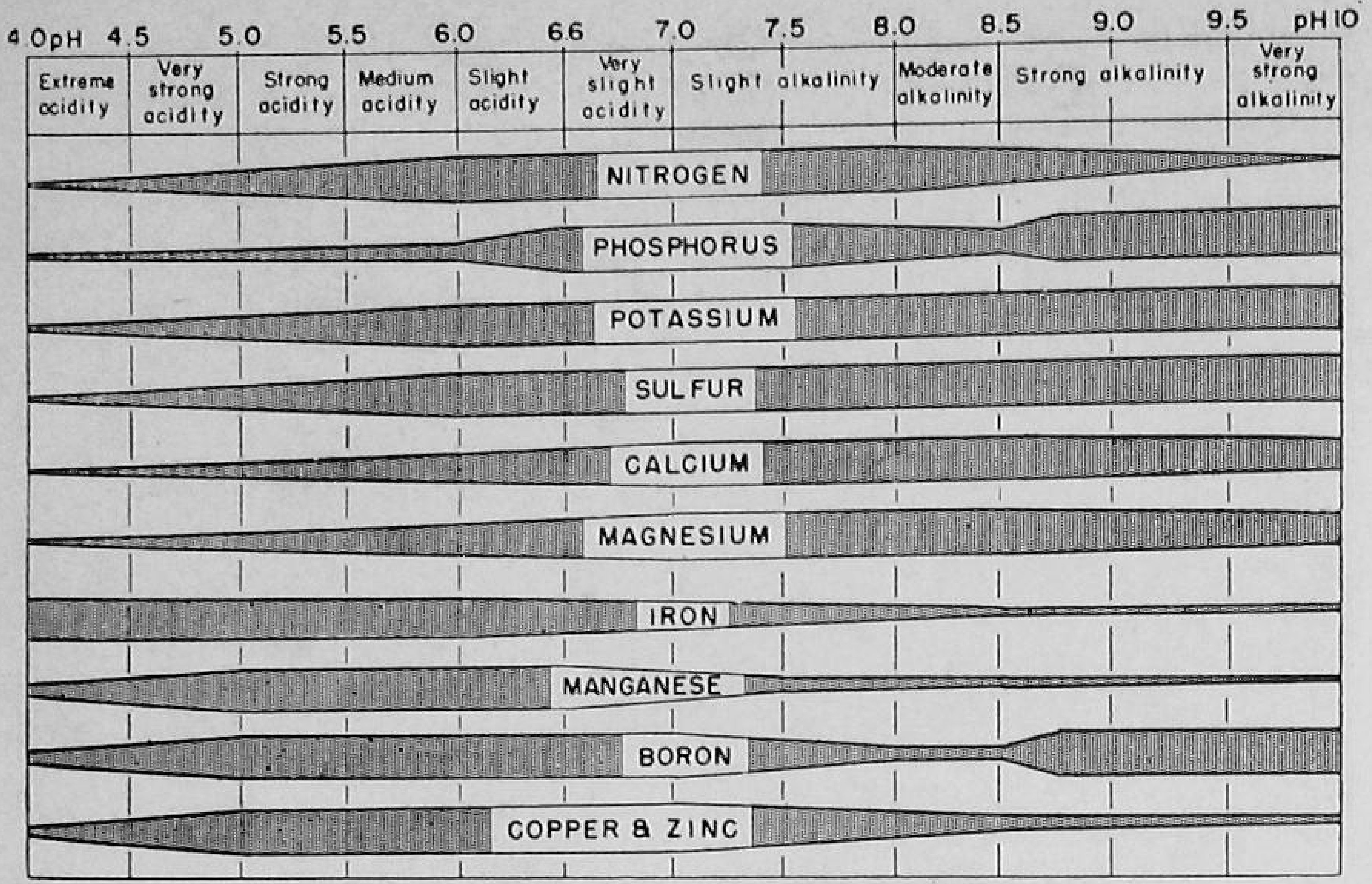
The number of effective combinations among soil types, crops, farming systems, and kinds of fertilizer in the world is almost infinite,

Photo No. 1. This picture illustrates one of the most common and most important effec of accelerated soil erosion on farm crops in regions of Podzolic soils. Here the friabl mellow surface horizons have been removed, and the new surface soil must be develope by tillage from the heavier, less friable B horizon. Because of the poor structure, the sc is poorly aerated, roots cannot develop properly, and plants quickly suffer from drough These spots of weak, yellowish plants are common on hilltops where erosion has bee active. (Grey-Brown Podzolic soil developed from loess overlying limestone in sout western Wisconsin, U.S.A.)

Photos by Charles E. Kellog

Photo No. 2. The pattern of soil use on the farm must be fitted to the soil pattern. He the sloping soils are too erosive for inter-tilled crops. Maize can be grown on the narro strips of Alluvial soils; yields are high if the crop is well fertilized. With the use of lim phosphate, and some potash on the sloping soils, excellent pastures of mixed grasses ar legumes can be grown. This farmer balances his pasture on erosive soils with the gra grown on the non-erosive soils. Proper fertilization makes this possible. (South-wester Virginia, U.S.A.)

AVAILABILITY OF PLANT NUTRIENT ELEMENTS AS INFLUENCED BY SOIL REACTION



This diagram illustrates the general relation between soil reaction (pH) and the availability of plant-nutrient elements, considering both direct and indirect effects. (See also page 93.) Each element is represented by a band as labelled. The width of the band at any particular pH value indicates the relative favourability of this pH value to the presence of the elements in readily available forms; the wider the band, the more favourable the influence. The total amount present is not necessarily indicated, however, since this is influenced by additional factors such as cropping, fertilization, and the chemical composition of soil minerals. Molybdenum, an essential element, is not included in the diagram because the relation of soil reaction to its availability has not been thoroughly investigated. Indications are, however, that liming and high pH promote its availability.

Diagram by E. Truog.

to say nothing of the number of wrong ones. Each farm problem is more or less individual for both farmer and adviser.

Many kinds of soil are not yet well understood. Soil research is urgently needed, especially in the tropics. Industrial research is progressing, and better and cheaper fertilizers can be anticipated. New explorations should lead to more sources and to new methods for concentrating materials of low analysis.

In the meantime, the need for making the utmost of our present supplies and knowledge to increase production on a sustained basis is urgent.

II

PLANT NUTRIENTS

Plants need sufficient nutrients in proper balance for normal growth and development.

From the air and water they take carbon, oxygen, and hydrogen. The *carbon* is taken in mainly through the leaves in the form of carbon dioxide, but small amounts of bicarbonate are also absorbed through the roots. As nearly half of a plant's dry weight is carbon, this element is very important. Carbon helps to build cell walls; it is an essential part of carbohydrates (sugars, starches, and cellulose) and is used in the making of proteins, fats, and other organic compounds. From 70 to 90 per cent of a plant's weight before drying is water. Ninety per cent of this weight is *oxygen*, which is often 40 per cent or more of the plant's dry weight. Oxygen enters importantly into the composition of carbohydrates, proteins, and fats; it is necessary within the plant's processes for the release of energy; and it is needed around the roots to assist in nutrient absorption. The *hydrogen* from water combines with carbon dioxide to form a variety of organic compounds.

From the soil, plants take relatively large quantities of nitrogen, phosphorus, potassium, sulphur, calcium, and magnesium. Some crops also take up large amounts of sodium. *Nitrogen*, which makes up 2 to 4 per cent of the dry weight of plants, is essential to new cell formation and is a basic part of proteins and of chlorophyll, the green colouring matter of plants. Indirectly, plants also receive nitrogen from the air through certain micro-organisms, the most important of which grow on the roots of legumes. *Phosphorus* is essential for the release of energy in plant respiration and is a constituent of certain compounds of living cells. *Potassium* aids in photo-synthesis, the process whereby chlorophyll, stimulated by sunlight, manufactures food within the plant. This element must be present also for the normal assimilation of nitrogen in the formation of protoplasm, the essential living part of plant and animal cells. In many plants *sodium* performs at least some of the functions of potassium. *Sulphur* is a constituent of all plant proteins. *Calcium* is necessary for the development of cell walls; its presence prevents injury to such actively growing cells as those at root and stem tips. The roots of plants having a calcium deficiency apparently do not readily penetrate the soil.

Magnesium is needed in small quantities for the formation of chlorophyll. It also aids in the movement of phosphorus within the plant. During the ripening period, for example, magnesium and phosphorus move together into the seed. That is why green plants deficient in magnesium may show a phosphate deficiency.

Elements taken by the plant from the soil in smaller amounts include *boron*, *iron*, *manganese*, *zinc*, *copper*, and *molybdenum*. These elements are present in adequate amounts in most soils, but deficiencies of each have been found in certain important soil types, the first five especially in calcareous soils (rich in calcium carbonate) and in soils which have been overlimed. Although the amount of these elements needed may be extremely small, lack of any one of them may seriously limit plant growth. As soils are built up in fertility, some addition of these nutrient elements is often found necessary to keep pace with larger yields.

Some plants are benefited by extremely small amounts of other elements than those mentioned here, and further research may find still other essential nutrients.

Each of the nutrient elements absorbed by the roots from the soil and by the leaves from the air has a definite function within the plant. Some of these functions, however, are still imperfectly understood. But plants also absorb elements which, according to our present knowledge, have no nutrient function.

The amount of nutrients needed for good yields varies from crop to crop. Table 1 illustrates this for six nutrient elements and a variety of crops. While the figures give interesting indications of relative amounts, they are of limited use because plants differ widely in their rooting systems and in their ability to assimilate nutrients from relatively insoluble components. For these reasons the total amount of nutrient elements contained in a crop cannot be used to calculate its fertilizer requirements.

Sources of Nutrients

Dry soil commonly contains 90 to 99 per cent mineral matter and 1 to 10 per cent organic matter. Both are primary sources of plant nutrients.

Many soils do not have a high natural degree of fertility for crop plants, especially soils of the humid regions, which are depleted by leaching, and some naturally fertile soils have lost their fertility from long periods of cropping. On either of these types of soil successful crop production depends on the addition of plant nutrients. Some of the most productive soils in the world have been made so, starting with relatively poor soils. Plant nutrients can be supplied by the use of:

Table 1. WEIGHT OF PLANT-NUTRIENT ELEMENTS CONTAINED IN COMMON CROP PLANTS WITH GOOD YIELDS[1]

Crop	Yield per hectare (Metric tons)	N	P	K	Ca	Mg	S
		(..	..	Kilograms	..	..)	
Maize	3·8	106	39	78	6	6	5
Oats	1·8	34	7	9	2	3	4
Wheat	2·0	56	22	34	10	4	4
Rice (paddy)	2·2	31	10	56	22	(²)	(²)
Soybeans	1·7	140	45	67	5	5	4
Lucerne (alfalfa) ..	6·7	157	39	151	136	17	18
Red clover	4·5	90	22	78	68	17	7
Tomatoes	22·3	112	39	196	17	20	22
Cabbage	33·6	112	28	121	49	11	78
Onions	22·4	(²)	20	115	30	10	46
Potatoes	20·2	140	39	190	3	7	6
Apples..	21·5	34	11	39	3	3	5
Grapes	9·0	28	11	39	2	2	1
Oranges	44·8	101	34	146	13	5	4
Tobacco	1·7	90	22	129	67	10	4
Cotton (seed and lint)	1·1 } 0·6 }	73	28	56	8	6	3

[1] The roots of plants have not been included in the calculations. For potatoes, both the tops and the tubers have been included. For trees and grapes, consideration has been given to the fruit, to the leaves, and to the yearly growth of wood.

[2] Suitable figures not available.

(1) Commercial fertilizers, including chemical and organic fertilizers.

(2) Manures, plant residues, animal wastes, and night soil, which also add organic matter.

(3) Green manures, which are crops grown for the purpose of adding organic matter to the soil, improving soil structure, and providing a steady source of nutrients as they decay.

(4) Soil amendments, materials like lime and gypsum, which are used primarily to correct unfavourable soil conditions such as high acidity or high concentrations of certain soluble salts; they also contribute the plant-nutrient elements, calcium, magnesium, and sulphur.

Availability of Nutrients

Although the intake of nutrients is greatest during the early and middle parts of the growth cycle, plants continue to absorb most of the elements in diminishing quantities as the crop matures. It is not enough, therefore, to supply the nutrients only at planting time; they

must be maintained in available form throughout the growing season. Maize, for example, uses nearly half of its nitrogen in mid-season. In humid regions it is rarely possible to apply enough nitrogen when maize is planted for best growth throughout the season. Supplemental dressings are necessary after the crop is well started.

In many soils, although the various nutrients are already present in sufficient amount, they are not in a form that can be immediately assimilated by plants. Only after relatively slow chemical and biological changes in the soil are these reserve supplies gradually unlocked and made usable. As soil minerals decompose, mineral elements such as potassium, calcium, magnesium, zinc, copper, and manganese become soluble. They are then held in the soil by the clay and organic matter, to some extent resistant to leaching, in forms of varying availability. Soils with a moderate to high content of clay and organic matter may be stocked with a fairly large reserve of readily available nutrients. Sandy soils commonly have a poorer supply of minerals and organic matter from which nutrients can be derived. Then, too, in sandy soils low in organic matter, nutrients are lost much sooner by leaching. On these soils the most efficient liming and fertilizing practices involve more frequent applications in smaller amounts.

Generally, more than 99 per cent of the nitrogen and as much as 50 per cent of the phosphorus in the surface soil are contained in organic matter. These nutrients are not immediately available for plant use, but with gradual decomposition they become so.

Severely eroded soils are usually deficient in both nitrogen and phosphorus. On the other hand, the supply of basic elements such as potassium and calcium in the subsoil sometimes equals or even exceeds that in the surface soil. For example, soils that are fairly acid at the surface may contain limy materials in the underlying subsoil. In fact, severe erosion may expose layers too rich in calcium for good plant growth.

Chemical changes within the soil reduce the availability of phosphates applied as chemical fertilizers. Phosphates are "fixed" by soil clays and by combining with calcium; that is, they go into chemical combinations from which the plant cannot readily extract and use the element phosphorus. Fixation is especially great in soils having an abundance of active iron and aluminum. The red and yellow soils of tropical and subtropical regions and even the subsoils of some acid soils in temperate regions are particularly high in aluminum and iron. The successful use of phosphates in these soils is an important problem. To some extent the fixation of phosphorus can be overcome by liming acid soils and by maintaining a good supply of organic matter.

However, too much lime lowers the solubility of phosphates; excess lime in irrigation water used on unleached soils of the semi-arid regions has raised this problem. To reduce fixation of phosphates, it is helpful to place the fertilizer in bands beside rows or in spots near the seed with a dibble. This reduces the amount of soil in contact with the fertilizer; the fixing power of the smaller amount of soil is soon satisfied, and the remainder of the phosphate becomes available to the crop. A larger yield results.

"Soil reaction"—acid, neutral, or alkaline—affects the availability of nutrients. Calcium and magnesium are the chief constituents of liming materials used as correctives of soil acidity. These elements are also plant nutrients, and they become more available for plant use after the acidity has been corrected. Two important biological processes in the nitrogen economy of the soil are favoured by soil reaction near neutrality. One is the fixation by soil micro-organisms of nitrogen from the air, which later becomes available to plants. The other is the conversion of the nitrogen in organic compounds into soluble forms readily available to plants. Potassium is also more available in neutral soils. Phosphorus is less available when the soil is very acid or when it is alkaline. Rock phosphate, because of its chemical nature, gives good response only on fairly acid soils. It is of little benefit to soils that are neutral to alkaline. The availability of sulphur is not influenced greatly by soil reaction.

The intake of elements required in small quantities—including boron, iron, manganese, copper, and zinc—is hampered in highly calcareous soils rich in calcium carbonate. Deficiencies of these elements, which occur particularly in organic soils and those of warm-temperate or hot regions, may be accentuated by very heavy applications of lime. On the other hand, as shown by experience in Australia, molybdenum becomes more available with the application of lime. Organic matter added to mineral soils helps to maintain the availability of iron. But copper deficiencies can be made more severe by increasing organic matter which is itself low in copper. In very acid soils, small excesses of aluminium and manganese may be toxic to plants. The whole matter of availability, especially of the elements needed in smaller quantities, can be highly complicated on some soils; both the farmer and the agricultural adviser may need the help of soil scientists to solve the more intricate problems.

The influence of soil reaction and associated factors on the availability of nutrients to plants is illustrated in the diagram facing page 7. The chart shows why overliming can cause the appearance of nutrient deficiencies. Of course, other things besides soil reaction also influence availability.

NEED FOR NUTRIENT BALANCE

Fortunately, plants can make good growth under a rather wide range of conditions, *if* enough of each nutrient is available. Some soils are seriously deficient in one or more elements, but a great number of soils furnish a balanced ration of nutrients at a relatively low rate. If conditions are so changed that the crop yield is greater, however, the soil that once supplied a balanced ration on a low level may become deficient in some nutrients. For instance, in a semi-arid region of the United States, where wheat and maize had been grown for many years by dry-farming methods without any need for added nitrogen, the system was changed to irrigation farming. The land was cropped to maize for two or three years and a serious nitrogen deficiency developed. The nutrients were balanced for dry-farming but not for the larger crops with irrigation. In this case the remedy was simple—addition of the necessary nitrogen.

Many soils are deficient in two or more nutrients. In such cases, the addition of one nutrient only may produce little or no increase in yield, but the addition of all the deficient nutrients produces a relatively large increase. The effect may be greater if all of them are added together than if they are added singly. An example can be taken from the state of Iowa (U.S.A.), where oats were grown experimentally on Ida silt loam, a shallow soil derived from calcareous loess. The soil is deficient in both nitrogen and phosphate. A dressing of nitrogen by itself increased the yield 118 kilogrammes per hectare. A dressing of phosphate by itself increased the yield 226 kilogrammes per hectare. A dressing of both together increased the yield 1,298 kilogrammes per hectare. This is an instance of the positive interaction of plant nutrients. Sometimes, however, for reasons not yet fully understood, the effect of adding all nutrients together may be less than the sum of the individual effects. This is called negative interaction. It is obviously a matter of practical importance to determine by experiment the responses of crops to fertilizers on particular soil types.

The application of one or more plant nutrients may accentuate the deficiency of another. For instance, a given soil supplies very little available potassium. To increase the size of the crop, nitrogen and phosphorus fertilizers are added without potassium. The plants in the larger crop have less potassium per unit weight and show more acute signs of potassium deficiency. It is commonly observed in English field trials that the tops of potatoes growing in plots that receive sulphate of ammonia and superphosphate scorch more severely and die down earlier than those left unfertilized, though final yields may be somewhat improved. Occasionally, the application of a

fertilizer or soil amendment actually brings about a reduction in yield because it accentuates an existing condition of unbalance. This has been shown by hydrangeas grown on a sandy alluvial soil deficient in potassium at the Antibes Agronomic Station (*Centre de recherches agronomiques de Provence*) in France. Irrigation water high in magnesium was used, which caused poor growth of the plants by further decreasing their uptake of potassium.

The capacity of soils to supply nutrients may change over a period of years, depending on the soil and its use. Soils that are originally highly productive may in time need additional nutrients for a balanced supply. On the other hand, heavy fertilization over a period of years may build up the supply of phosphate and potassium to the point where annual rates of application can be reduced without any appreciable reduction in yield. A balance of nutrients for the crops being grown is the goal. Fertilizer practices on the same piece of land may need revision from time to time to meet changing conditions.

Symptoms of Nutrient Deficiencies

Plants show characteristic hunger symptoms when any essential element is seriously lacking. Symptoms that can be detected visually include the kind of growth and the colouring assumed by various parts of the plant (see Frontispiece). The nature of the symptoms varies from crop to crop, it varies with the degree of the deficiency, it is sometimes confused by the effects of plant diseases and insect damage, and it may be complicated by the simultaneous appearance of two or three kinds of deficiencies. Long experience is required to diagnose the symptoms accurately and to write an effective fertilizer prescription. The agricultural adviser and extension worker in most cases will want to call in a specialist, but in some countries no specialist may be available. In that event, the field worker may wish to obtain one or two books on the subject, in which coloured photographs tell the story more effectively than words. Two that can be recommended are:

Hambidge, Gove (ed.) *Hunger Signs in Crops. A Symposium.* Washington: American Society of Agronomy and National Fertilizer Association, 3rd printing 1947. Pp. 327.

Wallace, T. *The Diagnosis of Mineral Deficiencies in Plants.* London: His Majesty's Stationery Office, 1943. Pp. 116. Supplement, 1944. Pp. 48.

A further complication in deficiency diagnosis is that recognizable symptoms usually appear only at an advanced stage of malnutrition and at an advanced stage of the plant's growth. Often the symptoms

become clear only after it is too late to correct the deficiency with fertilizers for the current crop. Especially on fruits, some deficiencies cannot be corrected by soil fertilization after the plants are well advanced in the season. This is particularly true with mature trees. On them, sprays containing iron, magnesium, or whatever element needs to be used are applied and the nutrient is absorbed through the leaves.

Symptoms of a deficiency in any given element are not identical in all crops, but a number of them are of general occurrence and importance. Those listed below, a minimum group, can provide only the barest introduction to this important subject.

The earlier symptoms of *potassium* deficiency are variously expressed in certain crops by small white, yellow, or reddish-brown spots on the leaves, followed by scorching or browning of the leaf edges in such crops as legumes, maize, cotton, and tobacco, and the leaf tips of small grains. In potatoes an abnormally dark green foliage is a dependable early sign, followed by browning of the leaves.

Nitrogen deficiency usually results in reduced plant vigour, in a fairly uniform light green or yellowish-green leaf colour, and in yellowing and dying of lower or older leaves.

Phosphorus deficiency often causes stunted growth, delayed ripening, poor fruiting, poor root growth, purpling of the leaves, leaf edges, or stems, and an abnormally dark-green leaf colour in some species, including tobacco and cotton. In addition to these symptoms, potatoes show rusty brown lesions on the tubers, first in the form of isolated flecks and then of larger areas as these join together.

Magnesium deficiency produces a yellowing (or reddening) which appears first at the tips and margins of leaves and spreads to areas between the leaf veins, especially of older or lower leaves. This symptom distinguishes it from iron chlorosis (loss of green colour), which usually starts in new leaves. Eventually the tissue of the affected leaves becomes brown. In maize, magnesium deficiency causes yellowish-white stripes to run the length of the leaves, with the veins remaining green. It may also cause an apparent phosphorus deficiency, especially in oil plants such as linseed and oil palm.

Calcium deficiency causes a distortion of new leaves. The growing point becomes stunted, and yellow and brown areas may develop along leaf margins and between veins.

Lack of *sulphur* results in reduced growth and in leaf-yellowing similar to that caused by nitrogen deficiency. It differs, however, in that it appears first on new growth, and the green veins are slightly more distinct than in nitrogen hunger.

Zinc deficiency causes splotchy yellow and brown leaf colouration,

sometimes with darkened veins. In maize, this deficiency causes dwarfing of plants. New leaves emerge whitish in colour (a condition that is commonly called "white bud"), and the upper leaves are yellow-striped between the veins.

Boron deficiency causes twisting and distortion of upper leaves and death of the terminal bud. Leaf points and margins may turn brown or reddish-yellow before drying prematurely. In some plants this deficiency causes brittle stems and petioles and internal blackening of fruit and root crops.

Copper deficiency is evidenced by wilting of upper leaves and dying of leaf tips, often without pronounced bleaching or change of colour.

In *manganese* deficiency the leaves may be chequered with yellow dead spots, or they may develop a light green colour between the veins, which later spreads over the entire leaf.

Want of *iron* causes leaves to lose green colour, especially the upper or new leaves, except along the principal veins, which remain green.

Toxic Effects of Excess Nutrients

For best growth and development, plants must have a balance of nutrients. They must have enough of each nutrient element to avoid deficiencies, but too much of any one can cause harmful toxic effects.

Large applications of fertilizer containing phosphorus, calcium, magnesium, and sulphur can generally be used with no harmful effects other than a possible lack of nutrient balance. Nitrogen and potassium, however, are generally applied in the form of highly soluble salts; large applications too near the seed may cause injury to germinating seeds and to the growth of seedlings.

Boron, copper, iron, manganese, molybdenum, and zinc are required by plants in very small amounts. Any addition of these elements beyond a narrow range of application is directly toxic to plants. Cauliflower grown on a sandy soil may need 2 to 5 kilogrammes of borax per hectare, but 10 kilogrammes per hectare would injure the crop. Beets and lucerne are noted for their relatively high boron requirement, but beans, which are often grown in rotation with these crops, are injured by any excess. Borax applications of 25 to 50 kilogrammes per hectare are common on beets and lucerne, and as much as 100 kilogrammes can be used on clay soils high in lime, but this is near the critical limit for beans. Highly organic soils are often deficient in copper. On such soils, somewhat larger applications can be used without toxic effects. Yet, on organic soils, excessive applications of either copper or manganese may lead to a deficiency of the other.

To avoid these dangers, rates of application should be governed by the nature of the soil and the needs of the crop.

Effects of Some Elements on Animals

Deficiencies or excesses of some elements which apparently have no effect on plants may nevertheless have harmful effects on animals consuming the plants. For instance, bush sickness in New Zealand and pining and other animal disorders in parts of the United Kingdom, Australia, Canada, and other countries have been shown to be due to a deficiency of cobalt in the soil. In New Zealand large areas of young soil from a certain pumice ash were, until recently, considered essentially worthless because cattle and sheep suffered severe bush sickness from eating the herbage on them. Now a relatively small amount of cobalt, added with the phosphate fertilizer, provides healthy pastures for both sheep and cattle (compare photos Nos. 3 and 4). The lands are being rapidly developed for good dairy farms. About 1 kilogramme of cobalt sulphate per hectare lasts 4 to 5 years, but smaller annual applications are recommended. Ordinarily about 3 kilogrammes are included with each ton of superphosphate. About 125 kilogrammes of the cobaltized superphosphate is used, plus 250 kilogrammes of ordinary superphosphate per hectare.

Iodine deficiency in feed grown on soil deficient in this element causes a goitrous condition in farm animals. This deficiency, reported in many parts of the world, can be cured by feeding iodized salt. Diseases of livestock have also been attributed to copper deficiency and to excess of fluorine.

"Teart disease" of cattle in south-west England is associated with excess of molybdenum in the soil, and losses of cattle from the same cause have been reported in several places in California and Florida, U.S.A. This condition can be countered by feeding copper sulphate.

Some plants absorb selenium more readily than others, and this element causes a fatal disease of livestock in certain regions of the world. In the United States it occurs in some plains areas, notably South Dakota, and is known locally as "alkali disease" or "blind staggers." No practical method has been found of eliminating selenium injury, either by dietary means or soil treatment, and areas where it exists have to be abandoned or only lightly grazed.

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III

THE NECESSITY FOR ORGANIC MATTER

SOIL organic matter is generally a good source of plant nutrients. It provides food for soil micro-organisms; during decomposition it helps to bring the mineral constituents of soil into solution; it improves the physical properties of soils.

Soil organic matter is derived chiefly from plant residues, but the remains of animal life also contribute to it. Grazing stock, worms, and innumerable kinds of soil insects all play a part in breaking down plant residues and disseminating them throughout the surface soil. Soils vary greatly in their content of organic matter, ranging from bog soils high in organic matter, to thin desert soils that have very little.

Chemically, soil organic matter is exceedingly complicated, varying from fresh material containing the same substances as the living organisms to products of decomposition of these substances.

During the decay of organic matter in the soil, nutrients are gradually released and changed into forms available to plants. As the organic matter decomposes, considerable quantities of carbon dioxide and some acids are produced. The carbon dioxide, when dissolved in soil water, together with the acids, helps to bring into solution minerals containing plant nutrients.

Humus, a dark mass of material variable in its composition but relatively stable, is that part of the organic matter in the soil that has lost its original identity through decay. Although humus organic complexes are decomposed more slowly than the fresh plant and animal residues, nevertheless nutrient elements such as nitrogen, phosphorus, and sulphur, which are contained in these complexes, are made available to plants through chemical and biological activities in the soil.

The humus also retains, in a form available to plants, the basic plant nutrients such as calcium, magnesium, and potassium and reduces their leaching out of the soil.

Organic matter improves soil structure. It promotes granulation—the grouping of soil particles. Well decomposed organic matter, especially, increases the cohesion of sandy soils, and coarse organic matter, such as straw, decreases that of clay soils. Thus, organic matter contributes to good soil tilth. Good soil structure and the

organic matter itself improve the water-absorbing capacity of soils, help to retain the water useful to plants, and also promote air movement and drainage in clay soils.

Micro-organisms exist in great variety and tremendous numbers in soil. Some decompose organic matter and release plant nutrients; some convert organic nitrogen to ammonia and nitrates which plants can absorb; others convert nitrogen of the air into forms which are later made available to plants. Many other activities are performed by different types of soil micro-organisms, but those mentioned are probably the most significant in relation to plant growth. Depending largely on soil conditions, there may also be unfavourable micro-organisms including denitrifying bacteria. Micro-organisms capable of producing antibiotic substances are also found in soils.

On farm lands, soil organic matter can be maintained by the liberal use of animal manures and composts, by green manuring, and by including legume crops, pastures, and hay in rotation.

Animal Manures

Animal manures are the solid and liquid excreta of livestock, generally mixed with a certain amount of litter, such as straw and peat, which has been used as bedding for the animals. The importance of manures as a source of plant nutrients and organic matter cannot be over-emphasized. Not only the manure produced in the barns and stables, but also the droppings and urine of grazing animals must be considered. In many parts of the world the farmers rely solely on animal manures for the maintenance and improvement of soil fertility.

On livestock farms, many crop residues that are not suitable for other uses can be used in feeding and bedding livestock, and the manure left on the farms by the animals is a valuable by-product of such management. Chemical fertilizers should be considered as supplementing animal manures on this type of farm. If the manure is well preserved, phosphate is the chief supplement needed, but nitrogen and potassium are often very necessary also.

Much has been written and said about the great value of manure and the importance of its conservation, but even now in many countries of the world this valuable resource is being wasted through neglect or improper handling.

Composition. On the average, fresh horse and cattle manures contain 20 to 25 per cent dry matter, 0·37 to 0·60 per cent nitrogen, 0·25 to 0·35 per cent phosphoric acid (P_2O_5), and 0·15 to 0·76 per cent potash (K_2O), besides significant amounts of other nutrients.

These figures are approximate because manures differ widely in their composition, depending on such factors as type, age, and individual characteristics of animals, milk production (with cattle), amount and digestibility of fodder and concentrates fed (the manure of animals subsisting on roughage is poorer in plant nutrients than that of those receiving high-concentrate rations), the amount and type of litter, time and type of storage, and method of handling.

Compared with commercial fertilizers on a unit-weight basis, animal manure is low in plant nutrients, especially in phosphorus. Thus it is customarily applied at relatively much higher rates than chemical fertilizers—probably 50 to 100 times higher.

The availability to plants of potassium in manure is equal to that in chemical fertilizers. On the other hand, only a fraction of the nitrogen in manure is soluble and immediately available like the nitrogen in chemical fertilizers. Much of the nitrogen in manure is in organic forms that are only slowly mineralized over a period of years. As a result, the effect of manure tends to be distributed over a longer time than that of chemical fertilizers. In temperate and cold climates the cumulative effect is increased with repeated applications of manure. But in hot regions, for instance in Southern Transvaal and other areas, no distinct residual effect of manure can be shown, nor is the carbon content of the soil increased by repeated manure dressings. In some areas this is readily explained by the quick consumption by termites of all cellulose in the manure.[1] In other areas the short-lived effect of manure can probably be explained by the rapid decomposition of organic matter that takes place under conditions of high temperature with alternating dry and moist spells.

The nitrogen of the urine, which represents 50 per cent of the nitrogen excreted,[2] is present in the form of simple organic compounds. These compounds are quickly decomposed by microorganisms to ammonia, which is readily volatilized. As a result, the conservation of urine nitrogen is one of the major problems in handling animal manure. It is lost through careless handling on many farms.

Storage. On most farms some storage of manure is inevitable according to the seasons of the year and the programme of work. Nor does the ploughing under of manure too long in advance of planting the crop always give good results. Although under certain

[1] C. W. Snow and H. Greene. "The Nitrate Profile in an Acid Soil," *Transactions of the Third International Congress of Soil Science*, Oxford, England, 1935. London: Thomas Murby & Co., 1935. Pp. 360–63.

[2] This is approximately correct for cattle. Urine nitrogen of horses, sheep and pigs represents approximately 37, 60, and 20 per cent of the total nitrogen excreted by these different types of animals.

Photo No. 3. Young soil from pumice ash in the Rotoura district of New Zealand, unused for many years because cattle and sheep grazed here suffered "bush sickness" due to cobalt deficiency.

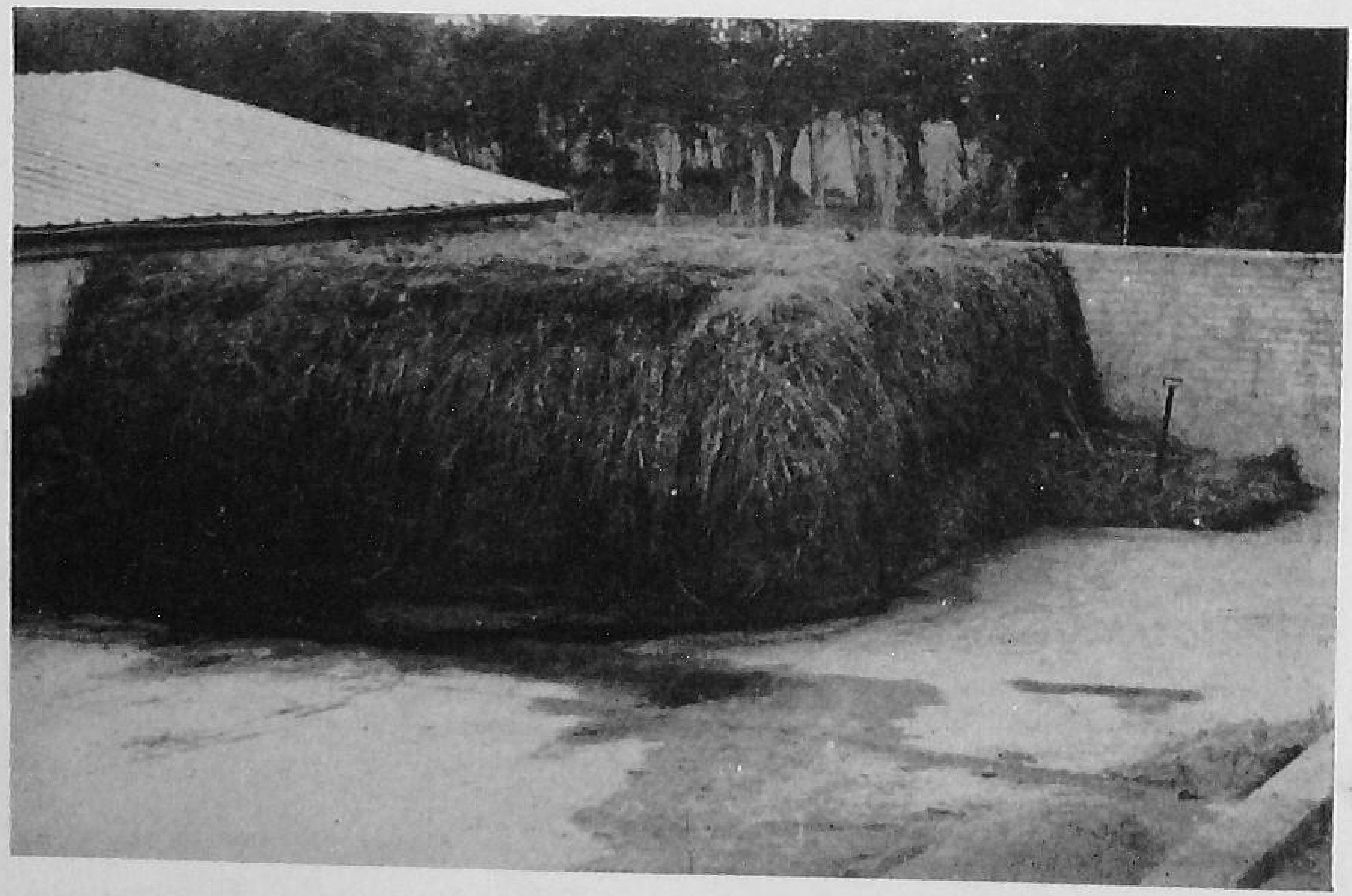
Photos by Charles E. Kellogg.

Photo No. 4. Young soil from pumice ash in the Rotoura District of New Zealand after development through the use of cobaltized superphosphate. In the development of this land the Manuka scrub was rolled and burned, the fluffy surface soil harrowed with heavy disks, the fertilizer added, and the area seeded heavily. During the first year red clover in the mixture made a heavy growth, and the land was undergrazed with beef cattle to tramp some of the clover into the soil and make it firmer. Subsequently, Italian rye grass and white clover were used dominantly in a permanent dairy pasture that yields about 135 kilogrammes of butterfat per hectare each year. Only one kilogramme of cobalt sulphur per hectare every four years is needed. It is put on, however, with the phosphate in smaller and more frequent applications. Since little supplemental feed is used here, it is easier and cheaper to add the cobalt to the soil than to the feed. The new soil gets 375 kilogrammes of superphosphate per hectare in the autumn; 375 kilogrammes again in the spring; and 375 kilogrammes annually thereafter in the autumn.

Photo No. 5. A poorly made manure pile. In rainy weather the plant nutrients are largely leached out, and in dry weather the losses of ammonia and organic matter are heavy. Such a manure heap is also an excellent breeding place for flies.

Photos by Karston Iverson.

Photo No. 6. A well-made manure pile, such as is usually seen in Denmark. Although the manure is not under a roof, losses of plant nutrients through leaching should not be great because the pile is well made and is on an impervious flooring. This type of manure pile keeps losses of organic matter to a minimum and is unlikely to become a breeding place for flies.



circumstances some rotting with consequent loss of organic matter may be desirable, the plant nutrients and organic matter are best conserved if the manure piles are thoroughly compact, moist but not too wet, and under shelter (compare photos Nos. 5 and 6). Manure should be kept in the same pile until it can be applied to the land; moving it from pile to pile results in much loss of organic matter and nitrogen. Moreover, well-compacted and sheltered manure piles are less likely to become a breeding place for flies.

Accumulation of manure under the feet of sheltered animals, bedded with just enough litter to absorb the liquid, is one of the most efficient and practicable methods for preserving manure. This practice, however, is not advisable with milking cows because of the increased danger of contaminating the milk. In Norway, where cattle are stall-fed throughout the winter, the manure is dropped during the daily cleaning through a trap door into a basement extending the length of the cowshed. In this manner it is well protected until used in the spring.

Where no provisions are made for urine to drain away into storage tanks, it may be lost through insufficiency of bedding. Loss of nitrogen and potassium is particularly serious when dairy cows are kept in barns with concrete floors that are frequently washed down with water. Where special steps are not taken to conserve the liquid manure, very serious losses may occur and the farm soils be impoverished. Losses of plant nutrients and organic matter from the manure heaps often occur through the draining away of the liquid which ordinarily accompanies rotting of manure and through leaching by rain. These losses can be avoided by using sufficient litter and by storing manure under shelter on impervious flooring. If the manure has to be kept in the open it should be built into high compact piles, so located that they receive neither roof nor surface water. Covering such piles with boards or soil affords additional protection.

In many of the western European countries, particularly in Denmark, Netherlands, France, and Switzerland, it is common practice to drain liquid manure into tanks and cisterns for storage. Separate storage of liquid manure permits much better control of nitrogen losses, which can be effectively decreased by floating a thin layer of tar or oil on the liquid and by covering the tank with a tight wooden cover.

The great number of changes that take place in a manure pile are chiefly due to the activity of multitudes of micro-organisms. Under the efficient methods of storage described above, which are largely anaerobic (free of air), the rate of decomposition of organic matter is slow and the volatilization of ammonia reduced to a minimum.

On the other hand, in dry, loose, well-aerated manure piles there is much loss of organic matter and ammonia.

Fresh versus rotted manure. Fresh manure containing much coarse carbonaceous litter such as straw may exert temporary ill effects on the soil. An abundance of fresh, energy-giving carbohydrate, like that in straw, stimulates the growth of micro-organisms. If these become very numerous, the availability of soil nitrogen to plants may be decreased. But once the material has been decomposed, the bacteria themselves die, releasing the nitrogen in their bodies to plants. Fresh strawy manure may be temporarily injurious on sandy soils by increasing further the drainage and aeration of such soils. These temporary ill effects, however, are to be weighed against the great losses of organic matter and nitrogen during the rotting of manure; and they can be partly or wholly overcome by ploughing under fresh strawy manure some time before the crop is to be planted. One definite advantage in favour of rotted manure is the fact that many weed seeds are killed in the process.

Use of preservatives. Considerable attention has been given in some countries to the use of preservatives on manure with a view to preventing losses of nitrogen in the form of ammonia. Of these, the most promising material is superphosphate. Its use in the barn gutter not only prevents nitrogen losses but also adds phosphorus, of which manure has comparatively little. The addition to the superphosphate of such elements as manganese, copper, zinc, boron, and molybdenum may also be of value in areas where deficiencies of these nutrient elements occur in the soil.

Calculations have to be made in advance of the amount of superphosphate to be used, which depends on the rate of application of the manure and the rate at which it is desired to apply superphosphate on the land.[1] Similarly, if other nutrient elements are added to the land with the superphosphate, precautions must be taken that they are not applied in too high concentration when spread with the manure.

Composts

A compost is a fertilizing mixture of partially decomposed organic materials of plant or animal origin, or both, and may include substances such as ash, lime, and chemicals. After composting, plant or animal refuse loses its original structure and undergoes drastic biochemical changes. Compost may resemble ordinary farmyard manure

[1] For example, assuming that a cow weighing 450 kilogrammes produces 8 metric tons of manure in seven months of barn feeding, and that 20 metric tons of manure and 200 kilogrammes of superphosphate per hectare are to be applied, it will be necessary to use 400 grammes of superphosphate per cow per day in the barn.

in appearance, composition, and fertilizing value. In fact, it is sometimes called artificial manure.

When there is a shortage or lack of animal manures, compost can fulfil a very useful function as a source of organic matter and plant nutrients. Moreover, the application of compost may be particularly helpful in ameliorating saline and alkali soils. In Japan, compost is a highly important source of plant nutrients; in 1946, when supplies of chemical fertilizers were low, it provided 47 per cent of the nitrogen, 66 per cent of the phosphate, and 64 per cent of the potash applied to Japanese soils. Compost is also used extensively in China. Compost has a special advantage in tropical countries because chemical fertilizers are often scarce or very expensive. Soils may be deficient in several nutrients, and organic matter is difficult to maintain in the soil. If compost is made from a wide variety of normal plants, it is likely to contain the essential nutrient elements in reasonably balanced supply.

There are several reasons for composting plant and animal refuse instead of applying them directly to the soil. The incorporation with the soil of large quantities of coarse plant residues, such as straw and stalks, which are rich in carbon and poor in nitrogen and phosphorus, may have temporary ill effects on both the chemical and physical properties of the soil, as explained in the section on *Fresh versus Rotted Manure*. The partial decomposition of such residues in a compost pile before application to the soil prevents these ill effects. By composting, the early decomposition occurs outside the soil in the heap. If the fresh materials are added directly to the soil, soil water is needed for this early decomposition. Where water is scarce, plants may thus be deprived of essential moisture. Then, too, the added compost tends to reduce water losses through evaporation and runoff, especially when used as a mulch or on the very surface. Composting also helps to destroy weed seeds and pathogenic organisms that may be present in the organic refuse. Furthermore, the major portion of the nitrogen and phosphorus contained in the materials used for composting is in organic combinations that are gradually changed to forms available to plants during decomposition in the compost heap and later in the soil.

Compost can be prepared from a variety of refuse materials available on farms, in village surroundings, or in urban areas, and several methods are used for making and protecting it (see photos Nos. 7, 8, and 9). For instance, on farms compost can be made from straw, sugar-cane refuse, chaff, rice hulls, forest litter, weeds, or miscellaneous crop residues by building above-ground heaps of these materials 1 to 1·5 metres in height. The sides should be slightly

sloping inwards and the top should be left flat or, in dry regions, with a slight depression in the centre to catch and hold rain. A good practice to follow with dry plant residues is to make a layer about 30 centimetres deep, wet this thoroughly with water, and pack it. This layer should then be covered by a layer from 5 to 15 centimetres thick of manure to which a little phosphate has been added. Instead of animal manure, earth and wood ash can be used or, if available, a solution of chemicals containing nitrogen and phosphate in appropriate amounts. Plant materials may be made into a good compost without manure or nitrogen and phosphate fertilizers, but the addition of these materials makes a better product and hastens decomposition. By alternating the layers as described, the compost pile is built up to the desired height. The top is then covered with a thin layer of earth to minimize loss of moisture and nitrogen. The heap should be left undisturbed for about three to four weeks, after which it should be given one or two turnings at monthly intervals to promote uniform decomposition. The compost is generally ready in three to four months.

In the Union of South Africa, the most suitable size for a compost heap is found to be 2 metres high, 2 metres wide, and 6 metres long. The refuse material is intermingled with small quantities of animal manure (5 to 25 per cent) and occasionally additions may be made of agricultural lime or ground rock phosphate. The material is well wetted and the heap is packed by trampling. If a fairly coarse product is satisfactory, as for instance in vegetable or fruit farming, the compost is ready in three to four weeks. If a finer material is required, the process may take two to four months. The heaps are not generally turned. The outside 15-centimetre layer, which dries out too soon, is usually discarded, and worked into the next heap. Raw rock phosphate is also commonly added to compost heaps of manure and crop residues in the Union of Soviet Socialist Republics.

In India, compost is made of alternate 5-centimetre layers of night soil and 20-centimetre layers of dry town refuse placed in trenches that are about 8 metres long, 2 metres wide, and 1 metre deep. After a trench is filled, the compost is covered with a 5-centimetre layer of soil and is allowed to decompose for a period of four to six months, after which it is sifted and applied to the land. Some work on composting municipal refuse in conjunction with night soil has also been done in the Union of South Africa.

A rapid method of composting urban refuse has recently been used successfully in India. It consists of pulverizing the material in crushers and then subjecting the mass to intensive microbial action under aerobic conditions for a fortnight. Composting of the organic urban

Photo No. 7. Cement-concrete compost pits at M'Vuazi, Belgian Congo. Cut-up banan plants, trimmings of legume cover-crops, and other vegetable matter are mixed with co manure in one pit. At weekly intervals this mixture is turned successively from one p to the next and finally on to the platform at the rear, ready for use in the field. At the tim the photograph was taken, a prepared batch of compost was lying on the platform, and new batch was being prepared in the partially empty pit. The floors of all the pits slop slightly toward the centre. Any liquid is collected in the central well, dipped out with bucket, and poured back on the organic matter.

Photo by Charles E. Kellogg.

Photo No. 8. In the left foreground is a protected compost heap in eastern Kwangtung South China. This compost is probably the usual mixture of pond or sea mud, hog an possibly human excreta, and rice hulls, well worked together.

Photo by Robert L. Pendleton.

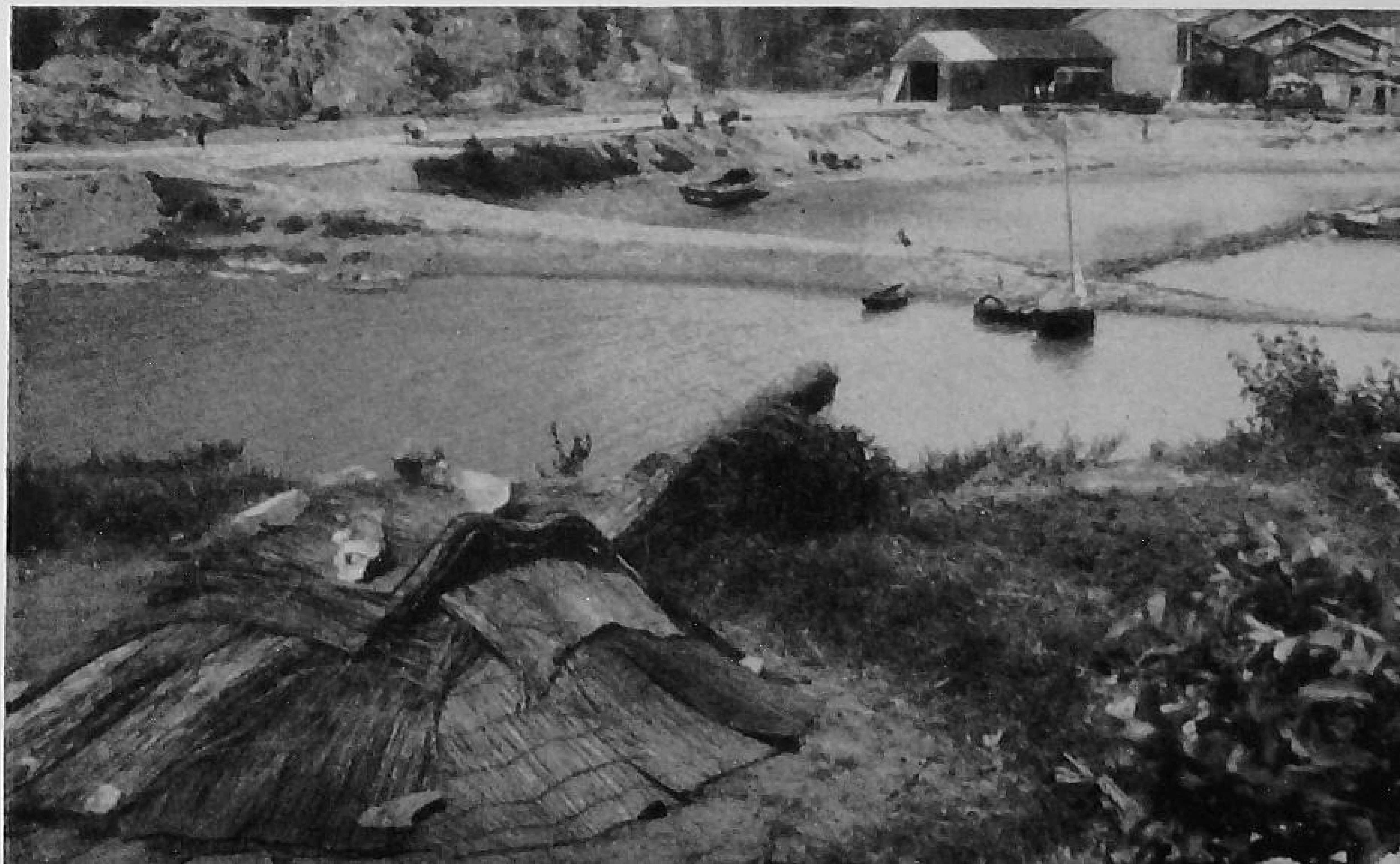


Photo No. 9. A circular compost heap in India, plastered over with earth to minimize loss of moisture and nitrogen.

Photo by C. N. Acharya.

Photo No. 10. Night soil from Hangchow, China, being carried along the Haining Road into the gardening district in open earthen jars.

Photo by Robert L. Pendleton.

refuse with sludges from modern sewage treatment plants may prove to be quite practicable on a large scale and would help to utilize for agriculture the city wastes which are now largely discarded.

The main drawback in compost-making is the amount of labour involved in collecting the refuse and in making the compost heap. In some areas an adequate supply of water is also a problem.

Night Soil

Night soil is human excrement, solid and liquid. In China it has been used in direct application to the land for more than two thousand years, and this practice has been one of the chief factors in the maintenance of China's soil fertility. At the present time 15 per cent of the plant nutrients applied to the soils of China through the use of human and animal excreta are derived from night soil. In Japan in 1945, night soil supplied 11·1 per cent of the total nitrogen, 4·1 per cent of the total phosphate, and 8·0 per cent of the total potash applied to the soil. In India, it is applied to a limited extent directly to the soil and, to a larger extent, is utilized in making composts. Night soil is also used in some European countries; for example, its use is quite extensive in the North of France around some of the populous cities. The excrement is stored for three or four months in pits until it dries. The dried material, which is frequently mixed with organic residues, is most often applied to pasture and vegetable crops.

In China the use of night soil in the wheat-growing areas of the North differs from that in the rice-growing areas of central and southern China. In the North, human fæces are added to animal manure and other refuse and the mixture is used on the land. The solid excreta are collected in towns and cities and made into cakes which are placed on the ground to dry, either without further treatment or mixed with small amounts of animal manure, soil, or ashes. After drying, which takes about a week, the "fæces cakes" are ready for sale. On an average these cakes contain about 9 per cent moisture, 59 per cent ash, 1·7 per cent nitrogen, 1·6 per cent phosphoric acid (P_2O_5), and 19 per cent carbon. There is considerable loss of nitrogen during the drying process. Human urine is not conserved generally in North China, but from the standpoint of plant-nutrient elements, especially nitrogen, phosphorus, and potassium, this is the most important portion of human excreta.

In the rice regions of central and southern China the fæces and urine are most commonly used together. On farms, solid and liquid excrement is collected in pits, often lined with brick and cemented with lime. It is carried into the fields in wooden buckets or is placed

in small storage pits at the edges of fields. The pits may be either open or covered with a roughly thatched roof. Plant refuse is often thrown into these pits so that a type of wet compost is formed. After long periods of storage the solid settles to the bottom. The overlying fluid may be dipped and applied separately, or the contents may be stirred and applied as a mixture.

On farms near urban centres the home supply of night soil is supplemented by material from the cities. Urban dwellers may use wooden buckets, earthenware jars, or a pit latrine for sanitary purposes. The contents are collected by farmers or dealers (see photos Nos. 10 and 11). The latrines and the methods of collection and storage of night soil, both in town and country, are not as a general rule sanitary. As a result there is general pollution and access of flies to the excreta.

By experience, farmers have learned that, before application, night soil must be diluted or must undergo a process of "ripening" or fermentation to minimize the possibility of damage to seeds or plants. The time of fermentation varies from a few days to several months, depending on the need for night soil in the fields. In spring and autumn, when crops are sown, the demand is greatest. Thus, the two storage periods are during the winter and summer; but even during these periods some night soil is used for top-dressing.

From a hygienic standpoint it is also advisable to have a certain minimum time of storage. This is of importance as a means of destroying pathogenic bacteria and parasitic worms. But it is difficult to prevent the farmers from using the night soil whenever the crops require treatment. Moreover, as fresh night soil is constantly added, the pits contain a mixture of fresh and fermented material.

In Japan, farmers customarily store fresh night soil in concrete or wooden tanks or barrels for varying lengths of time before application. The tanks are usually buried in the ground, covered and shaded. This practice tends to prevent loss of nitrogen as volatile ammonia. As a further measure to conserve ammonia, the addition of from 3 to 5 per cent superphosphate is recommended.

During even good storage conditions of night soil, nitrogen and organic matter are subject to losses. Other plant nutrients are not liable to be lost except through seepage of liquid out of poorly constructed pits or tanks. The organic nitrogen compounds of urine and fæces undergo biological decomposition with the formation of ammonia compounds and ammonia, which are quite readily volatilized. The organic nitrogen compounds of urine, which represent by far the greatest portion of nitrogen excreted, are decomposed much more readily than those of fæces. Prolonged storage under

poor conditions with over-exposure to sun and wind and with seepage of water into the pits may result in a low nitrogen content of night soil. Experiments in China show that, under poor storage conditions, fresh night soil containing 0·6 per cent nitrogen lost more than half of its nitrogen during eleven weeks of storage. Under good storage conditions for 16 weeks only one-seventh of the nitrogen was lost. Less nitrogen appears to be lost when fæces and urine are stored together than when they are stored separately. Average plant-nutrient content of fresh night soil from Japanese figures is 0·51 per cent nitrogen, 0·10 per cent phosphate (P_2O_5), and 0·23 per cent potash (K_2O). The content of organic matter is from 3 to 5 per cent and of ash from 1·4 to 1·7 per cent.

Hygiene. It is well established that much of the human death toll of China, as well as ill-health and misery, is due to diseases spread by human excreta. These include bacterial ailments such as cholera, enteritis, bacillary dysentery, and typhoid and paratyphoid fevers; protozoan diseases such as amoebic dysentery and diarrhœa; and intestinal worm diseases such as hookworm and ascaris.

The use of chemical fertilizers to replace night soil would greatly reduce the spread of disease. On the other hand, desirable as this change might be from the hygienic standpoint, countries such as China may be unable for a number of years to develop a fertilizer industry adequate to supply their needs. Moreover, if hygienic methods can be devised for utilizing night soil, the material can continue to be a good source of organic matter and plant nutrients. An immediately practical solution would be to use the following hygienic methods:

(1) Night soil should be protected from flies, and fly breeding should be controlled;
(2) It should be stored in such a way that it does not pollute the supply of drinking water;
(3) Pathogens, protozoan cysts, and worm eggs should be destroyed before the night soil is applied to the soil.

Improved methods of handling night soil. To prevent fly infestation in households, better latrines with automatically closing covers need to be designed. For collecting night soil, well-made and securely covered buckets, or, even better, large tanks should be used. Storage should be in well-built, closely covered pits. These measures would exclude flies, make the handling of night soil less offensive, and reduce nitrogen losses.

In Japan the collection and transportation of night soil in closed

containers (see photo No. 12), and its storage in covered pits or tanks has undoubtedly helped to reduce the number of flies in that country.

There is reason to believe that a storage period of several weeks destroys the pathogenic bacteria and protozoan parasites in night soil. A storage period of several months destroys ascaris and hookworm eggs or leaves them attenuated. The simplest method of assuring an adequate storage period is to have on hand enough storage pits to permit rotational use. At a given time some of the storage pits would be in the process of being filled, others would be undergoing the necessary storage period, and still others would be ready to empty.

Composting under aerobic conditions, used in India, Japan, and the Union of South Africa, is another method of handling night soil. Experimental results in China have shown that when night soil is mixed with an equal weight of rice straw, the internal temperature of a properly made compost heap rises rapidly and remains high for a long enough period for complete destruction of ascaris eggs and for partial control of fly breeding. No serious loss of nitrogen results. The outside of the compost heap, which does not heat, is trimmed off and used to prepare the next heap. Where a mixture of fæces with horse and cow manure is composted with straw, nitrogen conservation has been found to be better than where only fæces and straw are used. Aerobic composting of fæces and city garbage has proved successful in safeguarding the public health and in preserving fertilizer values.

One present difficulty with composting, at least in China, is the shortage of straw, which is used for feed, fuel, building, and other purposes. Where compost is produced in urban centres, there is the problem of transporting the bulky material to the farms.

Most of the night soil used in China and Japan is spread on the surface of the soil, where it is accessible to flies. Applying the night soil in furrows to be covered with soil would be a definite improvement in hygiene and should also increase the effectiveness of the night soil as a fertilizer. But very little experimental work has been done along these lines. It is highly desirable that more intensive research work be done in the immediate future, not only on sanitary methods of applying night soil to the land, but also on the whole important question of further utilization of night soil.

Sewage Disposal

The primary concern of sanitary engineers is the disposal of sewage in the least offensive manner, with a minimum pollution of streams and the greatest safety to human health. If they were equally concerned with the conservation of organic matter and plant nutrients in the sewage, a different approach to the problem and different

engineering designs would be used. But any new sewage disposal system would have to be as convenient and at least as sanitary as those now in use, and it would have to provide waste products to farmers in wholesome condition at low cost.

Water is used in modern systems of sanitation for the removal of human excreta and other wastes. Such a practice results in the dilution of materials in solution and in the dispersion of solids. In fact, water is the main constituent of sewage, amounting often to 99·9 per cent.

Practices of treating and ultimately disposing of sewage vary widely. Much of the sewage is emptied into natural bodies of water without any preliminary treatment or with only the largest solids removed. Some untreated sewage is still used for irrigation. On the other hand, sewage may receive some treatment to remove the greater proportion of solid material. The effluent liquid, which may be chlorinated or otherwise treated, may then be discharged into rivers and lakes or used for irrigation.

The coarse solids are removed by screening and are generally burned or buried. Fine solids and dispersed colloidal matter, which are removed by sedimentation or chemical precipitation, give rise to sludges. "Activated" sludges are of special value as fertilizers. Sludges may be digested to make them inoffensive and to reduce their volume and water content. Wet sludges are dumped into the sea or into low-lying places, or are used for fertilizer. Digested sludges and activated sludges may be dried before disposal. Dried sludges are used as fertilizer, burned, or used as fills for low ground.

More than half of the nitrogen, half of the phosphorus, and nearly all of the potassium are dissolved in the water. Thus, the loss of these nutrients is quite significant, even when the solids are retained. Only when raw sewage or sewage effluent is used for irrigation can the water-soluble nutrients be conserved. If this procedure is impracticable, it is difficult to recover the nutrients dissolved in sewage water because of their great dilution. In some locations, undesirable industrial wastes make the sewage entirely unsuitable for application to the land.

Sewage irrigation. The use of sewage for irrigation has been practised in Breslau, Germany, since the middle of the sixteenth century, and at Edinburgh, Scotland, for over two centuries. The most intensively developed sewage farms have been in the vicinity of Paris and Berlin. Before 1939 these cities had sewage-farm areas of 52,500 and 11,000 hectares respectively. Sewage irrigation is also practised in other countries, including Australia, India, South Africa, and the United States. Early sewage farms were irrigated with raw

sewage. For sanitary reasons, sewage now generally receives some preliminary treatment.

Conditions favourable for sewage irrigation are low rainfall, warm climate, sandy soils with good under-drainage, and cheap land. The benefit derived by the crops from sewage irrigation is due to the additional supplies of water, as well as to the plant nutrients and organic matter. Although rather large quantities of nutrients are added, the actual quantities available to plants are somewhat smaller because the great volume of water applied may leach out significant quantities of nitrogen, along with some potash.

Sewage-irrigated areas must rest a portion of the time to permit soil recovery and to allow harvesting of crops. The amount of sewage used on land varies greatly with such factors as supply of sewage available, porosity of soil, dryness of climate, and kind of crop. An annual depth of 275 centimetres could be taken as an example. This depth would dispose of 28,000 cubic metres of sewage per hectare and might provide quantities of plant nutrients as shown in Table 2. The figures given should be regarded merely as illustrative, however, because sewage varies tremendously in its composition.

The city of Johannesburg, Union of South Africa, operates several sewage farms. The broad features of sewage treatment are sedimentation and coarse filtration to remove the gross suspended material, aeration of the liquid effluent in tanks to provide a preliminary

Table 2. PLANT NUTRIENTS FURNISHED ANNUALLY BY IRRIGATION WITH RAW SEWAGE OR TREATED EFFLUENT

Plant nutrients	Quantity	
	Raw sewage	Treated effluent
	(Kilograms per hectare)	
Total nitrogen (N)	538	323
Phosphoric acid (P_2O_5)	151	81
Potash (K_2O)	108	81

purification, and grass irrigation to provide the final filtration and purification. The periodic irrigation and grazing of Kikuyu grass (*Pennisetum clandestinum*) gives high yields of nutritious pasture. The grazing rental to neighbouring dairy farmers is on the basis of 3d. to 4d. per head per day. Recent plantations of poplar have also been tried to provide suitable timber for the manufacture of matches.

Sewage from the city of Melbourne, Australia, is used to good effect in the Metropolitan Farm, Werribee. The climate is warm and dry. (Mean annual temperature is 13·5°C; annual rainfall 440 millimetres, annual evaporation 1,113 millimetres.) The total area of the farm is

10,000 hectares, including 4,100 hectares of irrigated pastures. The sewage from the city of 1·2 million inhabitants amounts to about 86 million cubic metres per year. Storm water is excluded from the sewers. The sewage arrives at the Farm without any preliminary treatment except the removal of a considerable proportion of free fat. As a result of its passage through pumps and the long travel through the outfall sewer, practically all the solid matter is disintegrated.

There are three methods of treating the sewage:

(1) *Land filtration.* The sewage is applied to permanent pastures in rotation in accordance with normal irrigation methods. During the summer months (December to February inclusive) the rotation period varies between 18 and 23 days and consists of 1 day for watering, 3 to 5 days for drying, and 15 to 17 days for grazing. During the balance of the year the rotation period is increased according to weather conditions, and in the winter months little sewage is applied to pastures. The depth of annual application is approximately 110 centimetres. About 41 per cent of the total sewage is disposed of in this way.

(2) *Grass filtration.* This method is adopted to relieve the pasture areas during winter months. Sedimented sewage is allowed to flow slowly over the ground (not exceeding 400 cubic metres per hectare per day) through a heavy growth of grass and other suitable vegetation. These grass filtration areas operate continuously throughout the winter period and are not grazed until the summer, when they are no longer in use. Effluent in this process is permitted to discharge directly into collecting sewers. Some 1,000 hectares are used for this purpose.

Table 3. PERCENTAGE COMPOSITION OF SOIL ON DRY-MATTER BASIS

Plant nutrient	Percentage content		
	Before irrigation	After irrigation	
	1912	1924	1938
Nitrogen (N)	·13	·26	·50
Phosphoric Acid (P_2O_5)	·05	·17	·25
Potash (K_2O)	·15	·80	1·09
Lime (CaO)	·06	·32	·39

(3) *Lagooning.* After sedimentation, portions of the night peak flow and of the wet weather flow are purified in large lagoons having an area of 240 hectares and a capacity of 0·6 million cubic metres.

Grass filtration and lagooning take care of 59 per cent of the total

sewage. The purified effluent is collected into an enclosure system of open-air channels and is discharged into Port Phillip Bay.

The permanent pastures under irrigation are seeded to the following mixture:

Perennial rye	22·0 kilogrammes per hectare
Italian rye	4·5 kilogrammes per hectare
Wild white clover (N.Z.) ..	1·0 kilogrammes per hectare
Alsike clover	1·0 kilogrammes per hectare
Strawberry clover	0·6 kilogrammes per hectare

Some of the irrigated grass is cut for hay; oats are grown on some dry areas for supplemental feed for stock.

The soils vary from fairly pervious sandy loam and clay loam to a less pervious thin capping of loam over basaltic clay. That sewage irrigation has increased plant nutrient content of the soil is shown by the analysis in Table 3.

The marked improvement in soil fertility by sewage irrigation is dramatically shown by the stock-carrying capacity of the land. Before irrigation the area carried 1 to 2 sheep per hectare. Now the equivalent of 34 sheep can be carried and fattened per hectare. The average number of stock carried during 1948 was approximately as follows:

Cattle (beef)	12,600
Sheep	4,700
Horses	320

The cattle are mainly bred on the Metropolitan Farm and the sheep are purchased as required. After fattening they are sold on the open market. Horses are mainly held on agistment, but some are bred for Farm purposes.

Slight infestation of cattle with *Cysticercus bovis* (beef measles) is recorded. From April 1942 until August 1948, 1·96 per cent of purchased cattle and ·25 per cent of Farm-bred cattle have been rejected for this cause. The low percentage of rejects in the Farm-bred cattle is believed to be due to an immunity gained by an attack of this disease. The policy now is to breed all the required cattle on the Farm as far as possible. During a period of six years 32,446 head of cattle have been sold for human consumption. The health of the cattle is excellent, and the mortality rate from all causes is very low. Tuberculosis is practically non-existent. The health of the employees and their families has in no way been adversely affected by their

residence on the Farm. The odours on the Farm are unpleasant relatively few times a year under certain climatic conditions, and the flies are troublesome only sometimes during calm, hot summer evenings.

Sludges. A number of types of sludge are produced by the different methods of sewage treatment. They may be classified as follows: (1) settled sludge, produced by plain sedimentation; (2) digested sludge, resulting from anaerobic decomposition of sedimented sludges; (3) activated sludge, produced by a special rapid aerobic treatment of sewage that results in coagulation and settling of suspended materials; (4) digested activated sludge; and (5) chemically precipitated sludge.

All these types of sludges have been used in agriculture. During sedimentation, precipitation, and especially during subsequent digestion, sludges undergo biological decomposition with a loss of organic matter and nitrogen and with an increase in ash content. During digestion there is also considerable destruction of grease, making the sludges more suitable as fertilizer. In the activated sludge process there is loss of organic matter, but the final nitrogen content of the sludge is comparatively high.

Activated and digested sludges are sometimes dried in the air or by heat. During the air-drying of sludge, further losses of organic matter and nitrogen occur. If the sludge cake is slightly acid, it is claimed that there is no loss of nitrogen by heat-drying.

Composition of sludges. Sewage sludges vary considerably in their plant-nutrient content, depending on the composition of the sewage and the treatment it has received. The following percentage range on a dry-matter basis can be considered representative: Nitrogen 1·5 to 3·5, phosphoric acid (P_2O_5) 0·75 to 4·0, and potash (K_2O) 0·3 to 0·6. The nitrogen content of activated sludge is considerably higher, running about 6 per cent. Sewage sludges are very low in potash. As a variety of wastes go into sewage and as urban populations consume foods which are often brought from a number of agricultural areas and from long distances,the sludges may be a good source of nutrient elements like boron, manganese, copper, and zinc, which are required by plants in small quantities. Where much of the sewage is of industrial origin, relatively large amounts of iron, chromium, and zinc may be present. Occasionally the amount of iron is sufficient to make the phosphorus in the sludge less available to plants.

Sludges in fertilizer trials. Plant-growth experiments have been conducted with sewage sludges of various kinds, and generally show marked stimulation of plant growth from application of sludges. But further increase is usually obtained when chemical fertilizers are used

in addition. The principal value of sludges as a fertilizer lies in their slowly available nitrogen and phosphorus, although the amount of available phosphorus may vary widely according to the nature of the sewage and the process it has undergone.

Economics of sludge disposal. Except in a few instances, the monetary returns on dry sludges, whether air dried or heat dried, do not cover more than the cost of drying and processing the material for sale. In a few cases the returns are sufficient to cover the overhead charges. As far as the sewage plants are concerned, the disposal of sludges as fertilizer is a ready means of disposing of these materials at least cost. Because of transportation costs and difficulty in handling, wet sludges are usually furnished free of charge or at a nominal cost to near-by farmers.

Sanitation. The occurrence in raw sewage of intestinal parasites and organisms causing gastro-intestinal and other diseases has been repeatedly demonstrated, and epidemics have been traced to sewage-polluted water. Adequate knowledge is still lacking, however, as to the prevalence in sewage of these parasites and pathogenic organisms and as to their power of survival under different conditions.

The usual treatments of sewage and sewage by-products, including digestion and drying of sludges, reduce the number of pathogens and parasites but do not eliminate them. It is claimed that heat-drying the sludge destroys cysts and ova of intestinal parasites, as well as hookworm eggs, and greatly reduces bacterial content, with only the spore-bearing bacteria surviving. Many sanitary experts believe that dried sludge, especially heat-dried sludge, is safe enough to be used as fertilizer on any crop.

Although raw sewage has been used for irrigation in many countries, this practice cannot be generally advocated and it has to conform to local medical regulations. Irrigation with the effluent from sewage treatment plants seems safer, but the land so treated should not be used for raising crops such as vegetables and low-lying berries for human consumption in the raw state. It can be used for cereals, forage crops, and various animal feeds and for crops that require processing, such as sugar beets and sugar cane.

Undigested moist sludges are a health hazard. Many think, however, that three months after their incorporation in the soil there is no more danger from these materials. Nevertheless, the general recommendations made concerning the utilization on crops of the effluent from sewage treatment plants apply also to the moist sludges.

Sewage-disposal products have been utilized to some extent for agricultural purposes, but much greater use could be made of them to reduce the great wastage of these sources of plant nutrients and

organic matter. The development of processes that would yield dry sludges of high plant-nutrient content at low cost would help to increase their use as fertilizer.

Up to the present this problem has not been satisfactorily solved, partly because it has not received sufficient sustained attention. To be sure, considerable interest is displayed in the subject in emergencies, as during the last two world wars, when shortages of fertilizers developed. But when conditions become more normal and the need for sewage utilization is no longer acute, interest wanes because developments in other fields are more spectacular.

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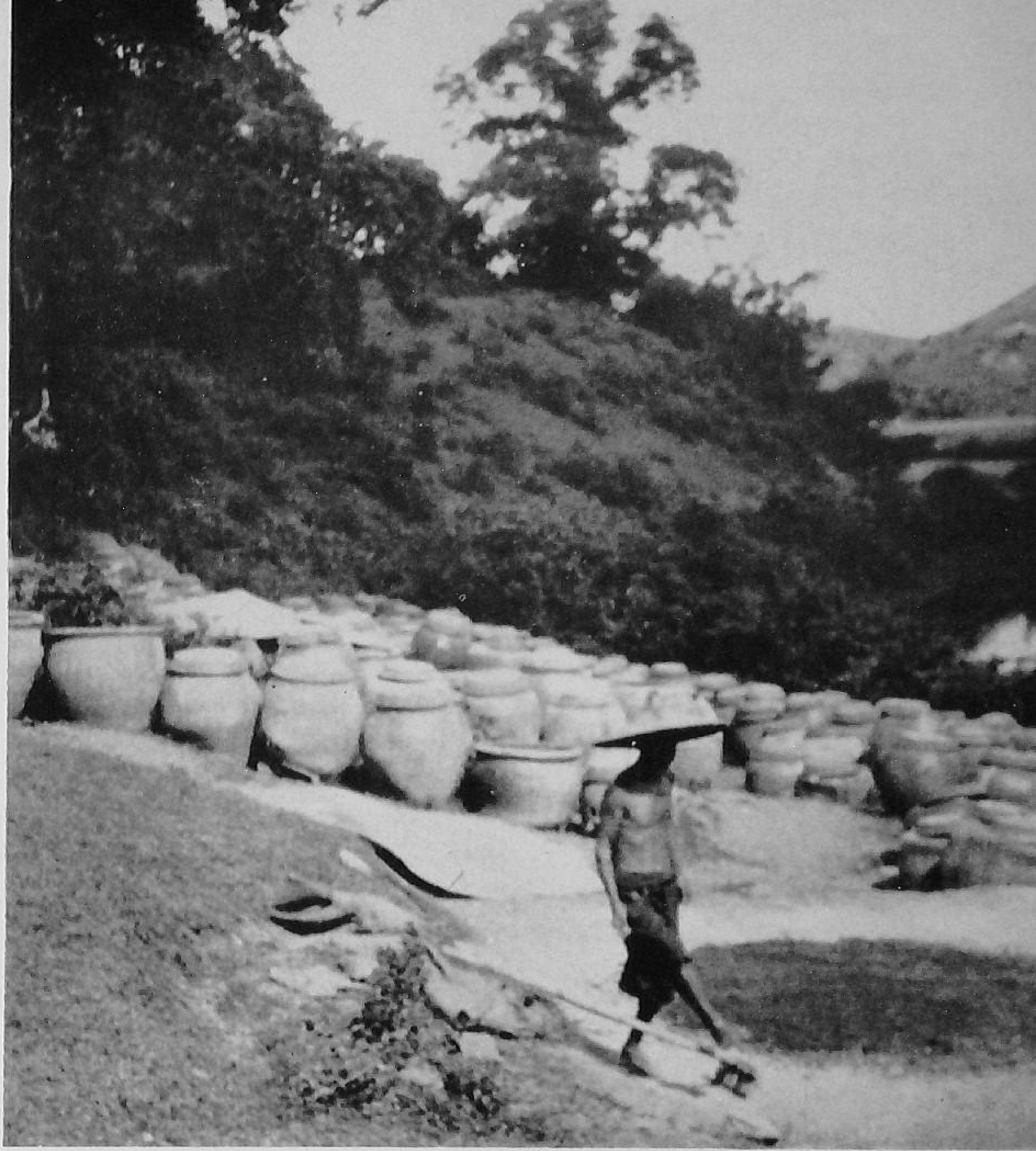

Photo No. 11. A fertilizer factory near Kochow, western coastal Kwangtung, South China. The night soil carried from the town is ripened in the jars with added water before being carried to the gardens for use. In the foreground some drier night soil is being mixed.

Photo by Robert L. Pendleton.

Photo No. 12. A common method of transporting night soil from the city to a farming community in Japan. These tightly covered containers are more efficient and more sanitary than open earthen jars.

Photo by C. L. W. Swanson.

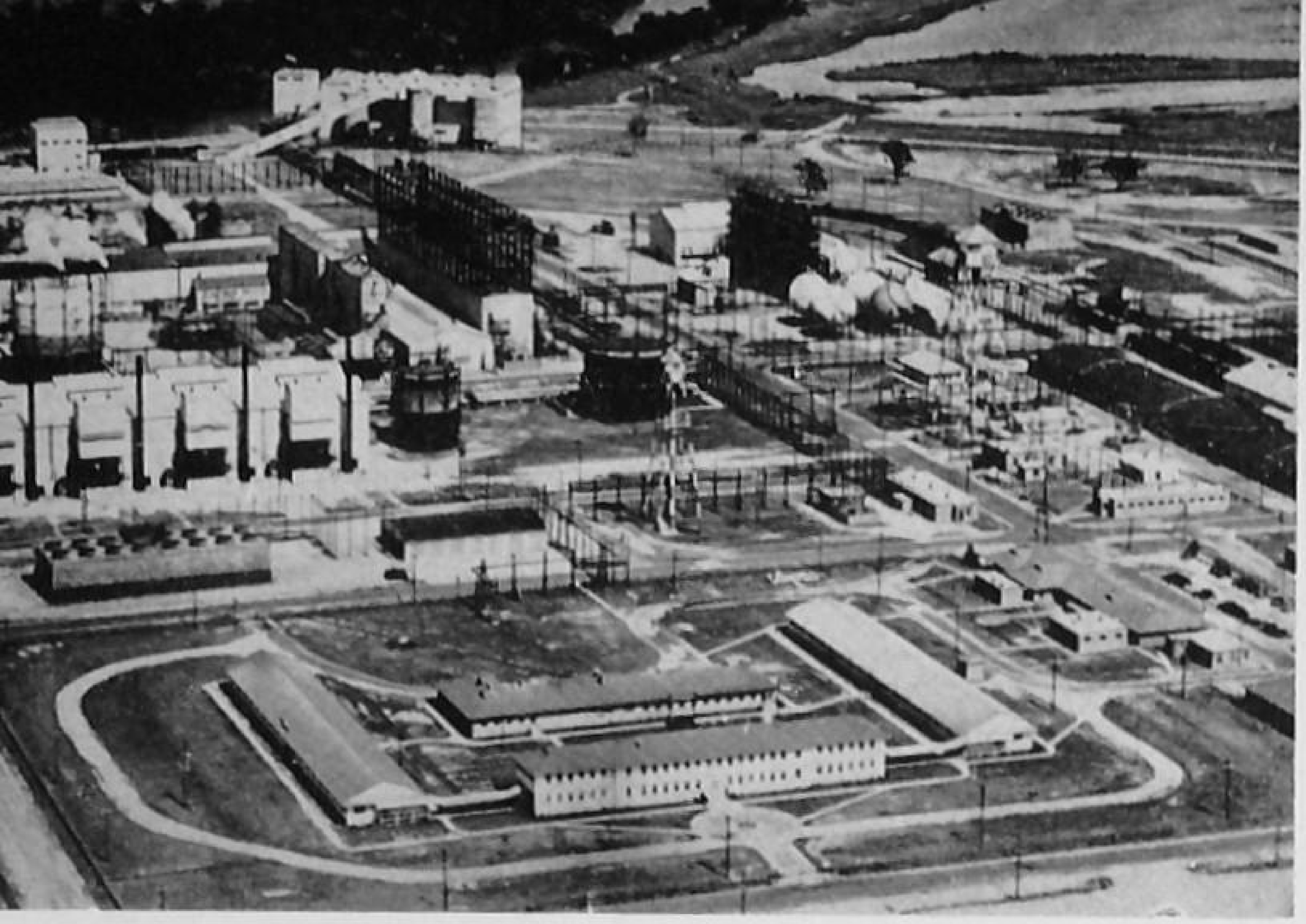

Photo No. 13. "Fixing" nitrogen of the air industrially. Aerial view of a synthetic ammonia plant. Nitrogen of the air is combined here with hydrogen to form ammonia, which is used to make nitrogen fertilizers such as ammonium sulphate and ammonium nitrate.

Photo by courtesy of K. D. Jacob.

Photo No. 14. "Fixing" nitrogen of the air on the farm. Clover plants, like other legumes, fix the nitrogen of the air through the action of bacteria present in their root nodules. The nitrogen is then available to the clover and to subsequent crops.

Photos by O. J. Kelly and R. Q. Parks.

IV

COMMERCIAL FERTILIZERS AND SOIL AMENDMENTS

COMMERCIAL fertilizers usually furnish one or more of the nutrient elements, nitrogen, phosphorus, and potassium. They are used primarily for the inorganic elements in them that are immediately available to plants or are easily made so under favourable soil conditions. They do not commonly include farm manures, composts, night soil, and other locally produced materials, chiefly organic in nature, which contain relatively small percentages of nutrient elements and which do not involve commercial processing or manipulation.

Soil amendments are chemical substances that influence plant growth favourably by producing in the soil some beneficial effect such as: (1) changing the soil reaction, that is, making the soil less acid or less alkaline as the case may require; (2) changing plant nutrients in the soil from unavailable to available forms; (3) changing the physical condition of the soil to a more favourable structure; and (4) counteracting the effects of injurious substances. Soil amendments usually contain plant nutrients. Agricultural liming materials, for example, furnish calcium and sometimes magnesium as nutrient elements.

PRIMARY SOURCES OF PLANT-NUTRIENT ELEMENTS

All three of the earth's great subdivisions—the *atmosphere*, the *lithosphere*, and the *hydrosphere*—are primary sources of one or more of the plant-nutrient elements. The atmosphere is the principal source of nitrogen; the lithosphere is almost the sole source of phosphorus; and the hydrosphere supplies important quantities of potassium.

Nitrogen. The air over each hectare of the world's surface contains approximately 78,000 tons of nitrogen—the only fertilizer raw material commonly occurring in the atmosphere. This nitrogen is present, however, in the elemental form and cannot be utilized directly by plants until it has been combined with other elements by chemical or biological means. Atmospheric nitrogen is the basis of the great chemical nitrogen-fixation industry and is by far the most important nitrogen resource. Furthermore, atmospheric nitrogen is the only fertilizer raw material of which every country has an adequate supply. On the farm, good use can be made of atmospheric

nitrogen for crop production by growing legumes (see photos Nos. 13 and 14).

The next most important source of fertilizer nitrogen is coal, from which ammonia is obtained as a by-product—principally in the manufacture of coke. In modern plants the average yield is about 2·3 kilogrammes of nitrogen as ammonia per ton of coal converted into coke. The bituminous coal deposits, widely distributed throughout the world, are estimated to contain at least 65,000 million tons of nitrogen. About 13 per cent of the nitrogen in coal is recoverable in connection with the manufacture of coke, and at least 85 per cent of the coal presently converted into coke is processed in by-product ovens.

Naturally occurring mineral nitrates provide the third most important source of commercial fertilizer nitrogen. Chile is the only country having large commercial deposits. The Chilean deposits probably contain more than 1,000 million tons of nitrogen, occurring chiefly as sodium nitrate mixed with other salts and with sand, clay, etc., from which it is concentrated by leaching, evaporation, and crystallization. Sodium nitrate is a preferred form of nitrogen in a number of crop-producing areas.

Animal by-products and plant residues, such as tankage, fish scrap, bird and bat guano, and oilseed meals, are important sources of fertilizer nitrogen in many countries.

Phosphorus. In the increasing order of importance, the principal sources of fertilizer phosphorus are bones, iron ores, and deposits of mineral phosphates—phosphate rock, or phosphorite, and apatite.

Bone is no longer a major source of fertilizer phosphorus in large areas of the world because of the discovery and development of large mineral phosphate deposits and because of its higher value as a phosphorus supplement in animal feeds. It is still, however, an important fertilizer in many countries that lack deposits of mineral phosphates or do not have well-developed chemical industries. Phosphatic slags obtained as by-products in the manufacture of steel from high-phosphorus iron ores are very important sources of phosphorus for European agriculture.

Phosphate rock or phosphorite, and to a less extent apatite, are by far the most important sources of phosphorus for commercial fertilizers (see photo No. 15). These materials are composed chiefly of one or more complex fluorine-containing calcium phosphates, insoluble in water but readily soluble in dilute acids. Deposits of mineral phosphates are widely distributed throughout the world. The total known reserve is estimated at approximately 26,200 million

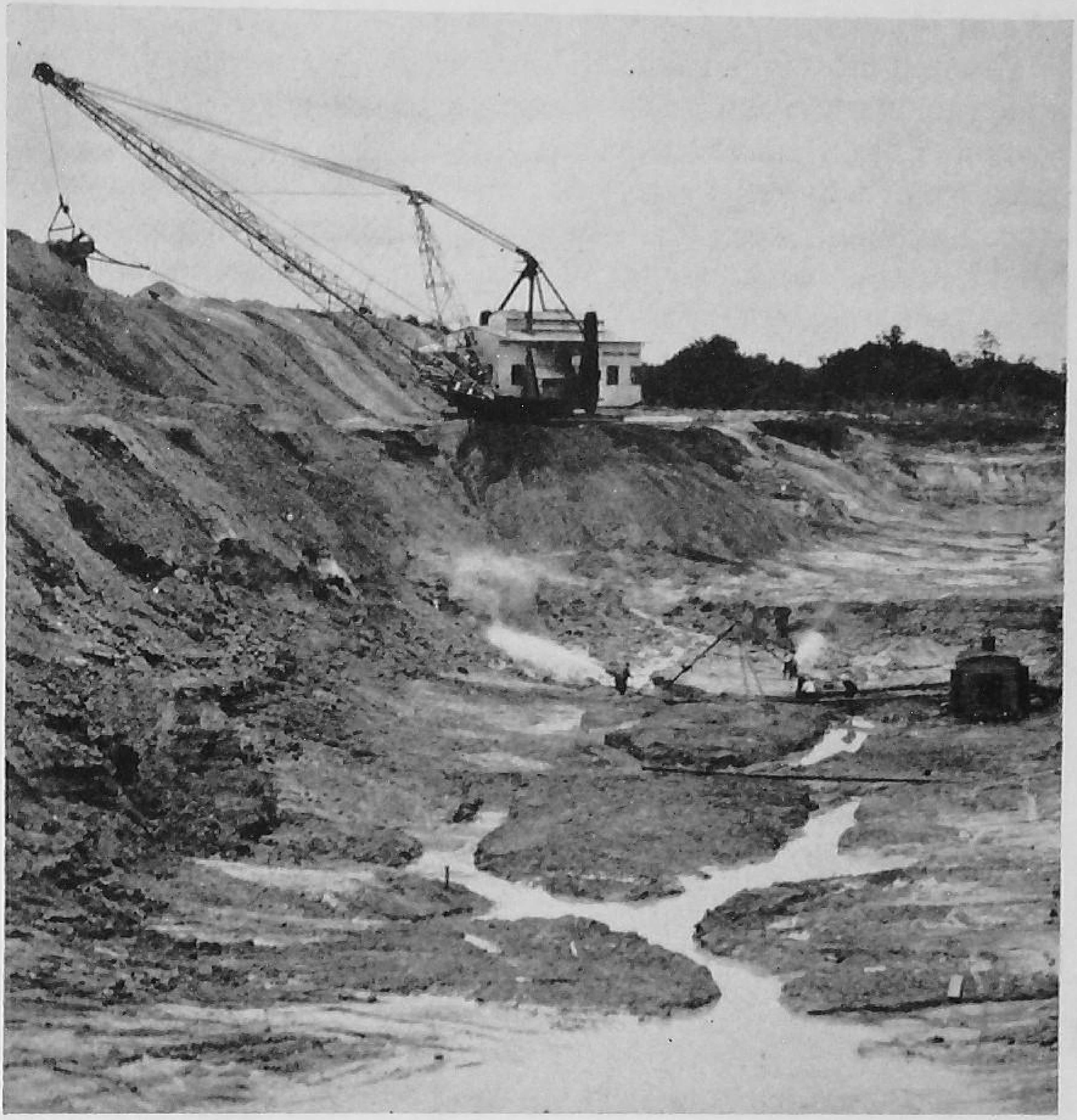

Photo No. 15 Mining phosphate rock in Florida, U.S.A.

Photo by courtesy of K. D. Jacob.

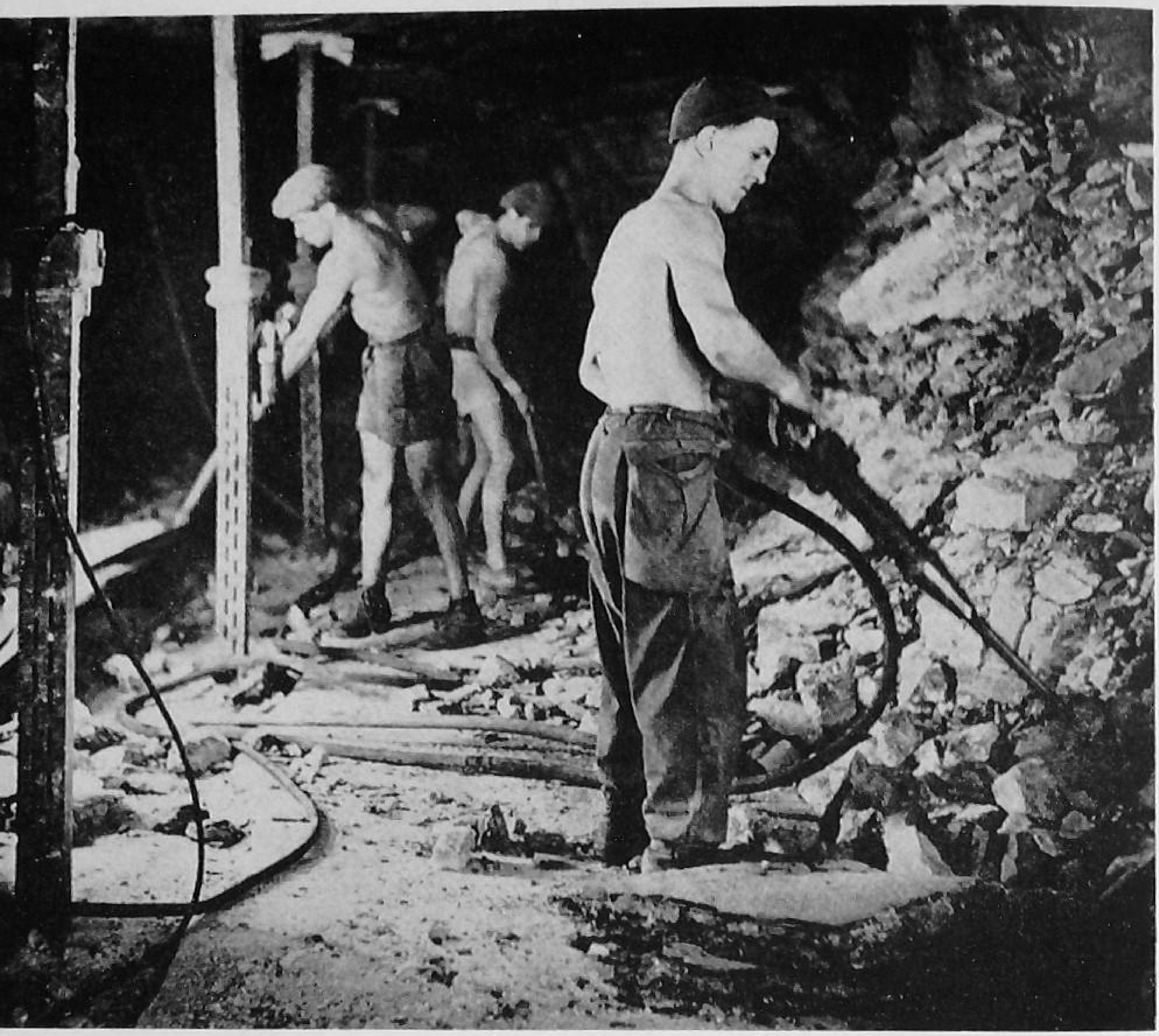

Photo No. 16. Loading potassium ore drilled in a shaft of a potash mine in Alsace, France.
Photo by courtesy of René Gide.

tons, containing about 6,400 million tons of phosphoric acid (P_2O_5).[1] About half of the known mineral phosphate is in the United States and the rest is principally in the Union of Soviet Socialist Republics and Morocco, Algeria, and Tunisia. Supplies have been developed in Egypt and certain of the Pacific Islands, notably Nauru and Ocean Island, and deposits—in many cases largely or totally undeveloped—occur in a number of other countries, including Brazil, French West Africa, Uganda, Canada, China, Mexico, Palestine, and Poland. Relatively little search has been made for phosphate deposits in South America, in Asia (except within the Union of Soviet Socialist Republics), and in much of Africa. For example, a locally important deposit has recently been found in Southern Rhodesia.

With some sources of phosphate rock, preparation of the material for the market requires elaborate screening, washing, and flotation treatment to separate the phosphate from clay, sand, and other impurities. With others, the phosphate is of commercial grade as it comes from the deposits. Although much ground raw phosphate is used directly as fertilizer in some countries—notably France, French West Africa, Netherlands East Indies, United Kingdom, the northern part of the Union of Soviet Socialist Republics, and parts of the United States—by far the greater portion of the mineral phosphate is converted by various chemical processes into forms that are more readily available to plants.

Potassium. Very large deposits of potassium-bearing rocks are widely distributed throughout the world, but economical processes for converting these materials into fertilizers have been developed only to a very limited extent in a few countries. For instance, some potassium fertilizers are being produced in Australia and Japan from alunite. Plant ash, cement-kiln dust, distillery waste from fermentation of sugar-cane molasses, and Steffens waste from the beet-sugar industry are minor sources of potassium for fertilizer. Extraction of potassium salts from Pacific Ocean kelps has been attempted, but without commercial success. Processes, not yet in commercial operation, have been developed for extracting potassium compounds directly from sea water.

Potassium fertilizer in the form of water-soluble salts is obtained chiefly from deep underground deposits and also from salt lakes (see photo No. 16). The total known reserve of potassium in this form is estimated at approximately 5,003 million tons of potash (K_2O), of which half is in Germany; in the descending order of

[1] The total possible reserve of phosphate rock has been estimated at a very much higher figure. For example, in French North Africa and Egypt alone, the possible reserve has been reported to be as high as 451,000 million tons of material containing 61,000 million tons of phosphoric acid (P_2O_5).

quantity, the remainder is mostly in Palestine, the Union of Soviet Socialist Republics, France, Spain, and the United States.[1] Deposits of soluble potassium minerals, apparently of considerable size, were recently discovered in Saskatchewan, Canada. Except in these countries, relatively little search has been made for deposits of these minerals; and even in these countries there is good foundation for the belief that careful investigation of the known and probable potassium-bearing areas will greatly enlarge the usable reserve of potassium salts.

Other nutrient elements. Nearly all countries have resources of *calcium*, chiefly in the form of limestone deposits. Additional resources in many areas include deposits of chalk, marble, marl, shells, and calcium sulphate.

The most important source of *magnesium* for fertilizer use is dolomitic limestone, which is widely distributed throughout the world. Other sources include lake brines, deposits in association with soluble potassium salts, silicate minerals, and magnesite (magnesium carbonate). Sea water contains a high percentage of magnesium, and economical processes for its extraction in the form of magnesium oxide for agricultural and industrial uses are now in operation.

The principal primary sources of *sulphur* are brimstone, pyrites and other metal sulphide ores, and calcium sulphate. With the exception of brimstone, these materials are widely distributed in large deposits. Though many countries have supplies of brimstone, the major developed deposits are in the United States, Italy, and Japan.

Boron, almost entirely in the form of borax, is produced chiefly in the western part of the United States. Other countries having commercial deposits include Argentina, Chile, Italy, and Turkey.

Only small quantities of *copper*, *iron*, *manganese*, and *zinc* are used as fertilizer. The primary sources of these materials are ores, from which they are recovered principally by the metal-mining and processing industries.

In some countries and areas where the soils are deficient in some of the plant-nutrient elements required in small quantities, salts of these elements are frequently added to the fertilizers in common use. For instance, in parts of the United States, salts of boron, copper, zinc, and manganese are often added to mixed fertilizers and in the eastern states borax is mixed with some of the superphosphate. This practice has also been used in Germany. In South Australia salts of copper, molybdenum, and zinc are used singly or in groups

[1] Some authorities estimate the deposits of water-soluble potassium salts at a much higher figure than this; according to some estimates, also, the potassium deposits in the Union of Soviet Socialist Republics are vaster than those in Germany.

of two or three with superphosphate; and in parts of New Zealand, cobalt is added to phosphate fertilizers.

Fertilizer Manufacturing Processes

With the exception of natural organic products and water-soluble substances, fertilizer raw materials usually require chemical processing in order to convert the nutrient elements into forms that can be readily utilized by crops. In particular, atmospheric nitrogen must be converted into compounds with other elements, and mineral phosphates need to be treated to increase the availability of phosphorus to plants. How the change is accomplished depends on a number of factors, including the availability and cost of fuel and electric power and of the necessary chemical reagents. Since potassium fertilizers are generally obtained directly from water-soluble raw materials, they usually need little or no chemical processing, but often require elaborate processes of purification and concentration.

Fixation of atmospheric nitrogen. In the increasing order of importance the three commercial methods for chemical fixation of atmospheric nitrogen are the arc process, the calcium cyanamide process, and the synthetic ammonia process.

The arc process, of which little or no use is made at the present time, involves the production of nitrogen oxides by heating air at the high temperature of the electric arc, and their subsequent conversion into nitric acid and nitrate salts. The process requires large quantities of electricity—some 67,000 kilowatt-hours per ton of nitrogen fixed—and its operation has been economically feasible only at sources of very cheap hydro-electric power, as in Norway. In a recently developed process, not yet in commercial operation, the high temperature required for the direct union of nitrogen and oxygen is obtained by means of a gas flame. The process is said to be a low-cost method for fixing nitrogen in areas having cheap supplies of gas.

In the cyanamide process nearly pure nitrogen is caused to react with calcium carbide. The product, calcium cyanamide, is generally used directly as a fertilizer. Manufacture of the calcium carbide requires coke, lime, and electric power. Cheap electricity is needed for economical production of calcium cyanamide, although the power requirement of the process is only one-fourth that of the arc process.

The synthetic ammonia process involves the reaction of pure nitrogen and hydrogen under high temperatures and pressures to produce pure anhydrous ammonia, which is subsequently converted into fertilizer compounds or which can be used directly as a fertilizer under certain conditions. As hydrogen, the more costly raw material, is produced readily with coal, coke, charcoal, or natural gas, the

process is adapted to use in any country having supplies of these materials. The hydrogen can also be produced by electrolysis of water, but in this case a cheap source of electricity is necessary, because the total power requirement per ton of nitrogen fixed with electrolytic hydrogen is only a little less than that for the cyanamide process.

Fertilizers from mineral phosphates.[1] Four general types of chemical processes are in commercial use for production of fertilizers from mineral phosphates. In the increasing order of present importance these processes are as follows:

(1) Treatment of the raw phosphate with silica and water vapour in furnaces, whereby most of the fluorine is driven off and the phosphorus is converted into forms that are soluble in neutral ammonium citrate solution but practically insoluble in water. Products of this kind, "defluorinated phosphate," include the fused tricalcium phosphate made by the Tennessee Valley Authority in the United States.

(2) Treatment of the raw phosphate at high temperatures with sodium salts or magnesium silicate to produce citrate-soluble phosphates. The products include Rhenania phosphate and Roechling phosphate made in Germany. A product having high fertilizing value is made on a limited scale in the United States by fusing and quickly cooling a mixture of phosphate rock and serpentine or olivine.

(3) Treatment of the raw phosphate with silica and coke in furnaces to produce elemental phosphorus, which is subsequently converted into concentrated fertilizer materials such as double or triple superphosphate, calcium metaphosphate, and ammonium phosphates. The power requirement of the electric furnace process is approximately 13,000 kilowatt-hours per ton of elemental phosphorus.

(4) Treatment of the raw phosphate with acids. These are the oldest and still most important processes for making phosphate fertilizers. The products obtained with the aid of sulphuric acid are chiefly ordinary or normal superphosphate, double or triple superphosphate,[2] and ammonium phosphates. In Europe, a great deal of phosphate rock is processed with nitric acid to make fertilizers in which much or all of the phosphorus is present as dicalcium phosphate. By means of the nitric acid process, synthetic ammonia can

[1] The Tennessee Valley Authority, Knoxville, Tennessee, U.S.A., has in press a book describing the advantages and use of several new processes for making some concentrated fertilizers. (Tennessee Valley Authority: *Soil, People, and Fertilizer Technology*, 1949).

[2] The manufacture of double and triple superphosphate and ammonium phosphate involves as an intermediary step the production of phosphoric acid from phosphate rock and sulphuric acid.

be utilized in the production of fertilizers containing nitrogen and phosphorus without the use of other chemicals such as sulphuric acid or soda ash. The power requirements of the acid-treatment processes are small.

Fertilizer Analyses

Fertilizers are commonly sold on the basis of the quantity and quality of their plant nutrients as determined by chemical analysis. For the most part the commercial value of fertilizers is assessed in terms of the nitrogen, phosphorus, and potassium present. Some fertilizers contain only one of these elements, while others contain two or all three of them. Many countries have adopted official methods for the analysis of fertilizers and for the approximate evaluation of their effectiveness in promoting plant growth.

In the analysis of a fertilizer, the quantities of the nutrients are always shown as percentages. The nitrogen content is nearly always expressed in terms of nitrogen (N), while the phosphorus content is commonly expressed as phosphoric acid (P_2O_5), and the potassium content as potash (K_2O).

All chemical nitrogen fertilizers are readily soluble in water and are commonly sold on the basis of their total nitrogen content. Evaluation of such fertilizers, especially in mixtures, may also require determination of the form of the nitrogen—ammonium, cyanamide, nitrate, urea, etc. The nitrogen in natural organic materials is chiefly insoluble in water, and there is no satisfactory analytical method for estimating the availability of such nitrogen, which may vary considerably with the conditions of its use. A declaration of the type of material and its content of total nitrogen must therefore be depended upon.

The value of phosphate fertilizers is tested by measuring the amount of phosphate soluble in water or in solutions of salts or acids intended to simulate the solvent action of plant roots. Neutral or alkaline ammonium citrate solutions or a 2-per cent citric acid solution is often used. The choice of the solvent depends on the type of the phosphate and the prevailing practices in the different countries. The soluble phosphorus determined in this manner is considered to be readily usable by plants and is commonly designated as *available phosphorus*.

Solubility in water is the usual criterion of the suitability of potassium materials for use as fertilizer. Frequently a small quantity of the water-soluble potassium fails to dissolve in water when the materials are contained in fertilizer mixtures, though it is still available to plants. A method has recently been developed for determining

available potassium in fertilizer mixtures, which consists in finding the quantity of potassium soluble in an ammonium oxalate solution.

Classification of Fertilizers

Fertilizers may be classified in several ways, depending on their sources, composition, characteristics, and uses.

Some fertilizer materials and all mixed fertilizers may be placed in more than one class. Thus, potassium nitrate is both a nitrogen and a potassium fertilizer, while the ammonium phosphates are both nitrogen and phosphate fertilizers. In some countries, such as the United States, fertilizers containing nitrogen, phosphorus, and potassium are commonly, though incorrectly, called *complete fertilizers*, as distinguished from those termed *incomplete fertilizers*, which contain only one or two of these elements. In France, the term *composé* (compound) is applied to fertilizers having more than one plant nutrient, and the term *simple* to fertilizers containing only one.

Commercial materials containing one or more plant nutrients in a form which in the soil becomes available to plants are termed *fertilizer materials* or *straight fertilizers* to distinguish them from mechanically prepared mixtures which are termed *mixed* or, in some countries, *compound fertilizers* or *fertilizer mixtures*. Thus, in some European countries the term *compound* may denote mechanically prepared mixtures as well as individual materials containing more than one plant-nutrient element. *Straight fertilizers* are commonly divided into two classes: (1) *chemical fertilizer materials*, consisting of more or less pure chemical compounds, and (2) *natural organic fertilizer materials*, consisting of complex vegetable or animal substances.[1] In some countries a further distinction is made between fertilizers of high and low plant-nutrient content, or between high and low analysis fertilizers.

In many countries, especially in Europe and Asia, farmers apply individual fertilizer materials to the soil at the appropriate times for the various crops. More recently European countries have been making somewhat greater use of mixtures of different materials, a procedure which has been followed for a considerable time in a number of countries, notably the United States, Canada, and the United Kingdom. In some countries perhaps too much emphasis has been given to mixed fertilizers. Farmers have used them when only

[1] The common use of the terms *chemical fertilizer materials* and *natural organic fertilizer materials* is unfortunate, because an impression is created that so-called chemical fertilizers are unnatural. Better terms which are sometimes used are *inorganic* and *organic fertilizers*. This classification also has its drawbacks, because certain materials, such as urea and calcium cyanamide produced industrially, are by chemical definition organic compounds, and yet in their solubilities and action in the soil they resemble the inorganic rather than the organic fertilizers.

one or two plant nutrients were really needed. In addition to mixed fertilizers applied at or shortly before seeding or planting, these countries also use large quantities of the individual fertilizer materials. The nitrogenous types are widely used for side-dressing and top-dressing growing crops, while it is common practice to apply phosphate fertilizers with legume seedings and as top-dressing for meadows and permanent pastures.

Mixed fertilizers are for the most part made and sold by fertilizer manufacturers, though some mixing is done on farms or in local co-operatives. The mixtures are frequently sold under trade or brand names, sometimes designed to catch the fancy of the purchaser. In making mixed fertilizers, the manufacturer usually includes at least four and sometimes as many as ten or more fertilizer materials.

While fertilizers are commonly applied to the soil in the form of solids, limited use is also made of gases and liquids, chiefly anhydrous and aqueous ammonia. Direct use is also made of gases and liquids in the preparation of mixed fertilizers. Anhydrous ammonia and its aqueous solutions, especially those containing ammonium nitrate or urea, are important sources of nitrogen for mixed fertilizers in the United States.

Acidic, basic, and neutral fertilizers. Fertilizers may be divided into three classes according to their influence on soil reaction, namely, (1) acidic or acid-forming, (2) neutral, and (3) basic or alkaline. The degree of acidity or basicity of some fertilizer materials is shown in Tables 4 and 5. The values were determined by a chemical method commonly used in the United States.

It has been well established that the continued use of certain fertilizers causes a residual acidity in the soil which, if not corrected, is eventually injurious to plant growth. Soils that are already fairly acid or sandy soils that are readily made acid are the first to show decreased crop yields. The soil-acidifying effect of fertilizers is due mostly to ammonium salts. On the other hand, sodium nitrate, calcium nitrate, and calcium cyanamide reduce acidity in the soil owing to the alkaline or basic effects of the sodium or calcium. Acidity can be overcome by liming the soil. For balancing the residual acidity of mixed fertilizers, it is a common practice in some countries to include limestone, preferably dolomitic limestone, in the mixtures.

The use of fertilizers that leave a basic or alkaline residue generally presents no serious soil problems except on feebly permeable heavy or alkaline soils liable to injury by the introduction of too much sodium.

Physical Condition of Fertilizers

The physical condition of a fertilizer is of major importance to its

Table 4. APPROXIMATE COMPOSITION OF CHEMICAL FERTILIZER MATERIALS

Material	Total nitrogen (N)	Total phosphoric acid (P_2O_5)	Available phosphoric acid (P_2O_5)	Water-soluble potash (K_2O)	Total lime (CaO)	Total magnesia (MgO)	Total sulphate (SO_3)	Equivalent acidity[1]	Equivalent basicity[2]
NITROGEN MATERIALS									
Ammonia, anhydrous	82·2	—	—	—	—	—	—	148	—
Ammonia solution[3]	20·6–24·7	—	—	—	—	—	—	37–44	—
Ammonium chloride[4]	24·0	—	—	—	—	—	—	128	—
Ammonium chloride-calcium carbonate (Kalkommoniak)	15·0	—	—	—	18·5	—	—	47	—
Ammonium nitrate (nitrate of ammonia)	32·5–34·0	—	—	—	—	—	—	60	—
Ammonium nitrate-ammonia solution[5]	37·0–40·8	—	—	—	—	—	—	67–73	—
Ammonium sulphate (sulphate of ammonia)	20·5	—	—	—	—	—	59·0	110	—
Ammonium sulphate-nitrate[6]	26·0	—	—	—	—	—	28·0	85	—
Calcium-cyanamide[7]	21·0	—	—	—	54·0	—	1·0	—	63
Calcium nitrate (nitrate of lime)	15·5	—	—	—	28·0	—	—	—	21
Calcium nitrate-urea (Calurea)	34·0	—	—	—	13·0	—	—	28	—
Cal-Nitro[8]	20·5	—	—	—	10·0–20·0	0–7·5	—	0	0
Sodium nitrate (nitrate of soda[9]	16·0	—	—	—	—	—	—	—	29
Urea (Uramon)[10]	42·0	—	—	—	—	—	—	75	—
Urea-ammonia liquor	45·5	—	—	—	—	—	—	82	—
PHOSPHATE MATERIALS[11]									
Basic slag, Bessemer[12]	—	17·5	16·0	—	47·0	4·0	0·5	—	([13])
Basic slag, open-hearth	—	86·0–16·0	5·0–15·0	—	45·0	5·0	0·5	—	([13])
Basic slag, open-hearth fluorspar	—	6·0–12·0	2·0–4·0	—	45·0	5·0	0·5	—	([13])
Calcium metaphosphate	—	64·0	53·0	—	23·0	—	—	0	0
Defluorinated phosphate rock [14]	—	20·0–30·0	18·0–24·0	—	28·0–42·0	—	—	—	([13])
Dicalcium phosphate[15]	—	40·0	39·0	—	32·0	—	—	—	25
Phosphate rock-magnesium silicate glass[16]	—	20·0	17·0	—	32·0	17·0	—	—	([13])
Phosphoric acid, liquid	—	54·0	54·0	—	—	—	[17]3·5	([18])	—
Rhenania phosphate[19]	—	27·0	25·0	—	40·0	0·5	—	—	([13])
Roechling phosphate[20]	—	20·0	18·0	—	32·0	1·5	7·0	—	([13])
Superphosphate, ordinary [21]	—	14·5–20·0	14·0–20·0	—	25·0–30·0	0·5	28·0–31·0	0	0
Superphosphate, double[22]	—	45·0–50·0	43·0–49·0	—	17·0–20·0	0·5	[23]2·5	0	0

POTASSIUM MATERIALS									
Alunite, calcined[24]	—	—	—	5·5	4·0	0·5	5·0	([25])	([25])
Bittern potash[24]	—	—	—	7·0	—	14·0	24·0	0	0
Cement-kiln dust[24]	—	—	—	5·5	45·0	2·0	18·0	—	([13])
Hard salt (hartsalz)	—	—	—	13·0	0·5	8·0	15·0	0	0
Kainite, including carnallite and sylvinite	—	—	—	12·0–22·0	0·5–5·0	0–15·0	1·0–25·0	0	0
Manure salts	—	—	—	25·0–40·0	0–1·0	0–6·0	0–13·0	0	0
Potash from cement-kiln dust[24]	—	—	—	25·0	28·0	1·0	31·0	—	([13])
Potash from distillery waste[26]	0·5	2·0	1·5	34·0	16·0	5·0	12·5	—	([13])
Potash from Steffens waste[24]	1·0	—	—	36·0	0·5	—	2·5	—	([13])
Potash from sunflower ash	—	—	—	63·5	([25])	([25])	0·5	—	([13])
Potash from wood ash[24]	—	—	—	51·0	([25])	([25])	6·5	—	([13])
Potassium carbonate (carbonate of potash)	—	—	—	65·0	—	—	0·5	—	([13])
Potassium chloride (muriate of potash)	—	—	—	48·0–62·0	0–3·0	0–3·0	0–7·0	0	0
Potassium magnesium carbonate (carbonate of potash-magnesia)	—	—	—	20·0	1·0	20·0	0·5	—	([13])
Potassium magnesium sulphate (sulphate of potash-magnesia)[27]	—	—	—	21·0–30·0	0–6·5	6·0–19·5	32·0–56·0	0	0
Potassium sulphate (sulphate of potash)	—	—	—	48·0–52·0	0–2·5	0–2·0	39·0–48·0	0	0
Quartz trachyte, calcined	—	—	—	4·5	([25])	([25])	([25])	—	([13])
NITROGEN-PHOSPHATE MATERIALS									
Ammoniated superphosphate, ordinary[28]	2·0–5·0	14·0–20·0	13·5–19·5	—	24·0–29·0	0·5	27·0–30·0	4–7	—
Ammoniated superphosphate, double[28]	4·0–6·0	44·0–49·0	42·5–48·5	—	16·5–19·5	0·5	[22]2·5	11–14	—
Ammonium nitrate-dicalcium phosphate[29]	20·0	20·0	19·5	—	14·0	—	—	25	—
Diammonium phosphate (Diammonphos)	21·0	53·0	53·0	—	—	—	—	74	—
Diammonium phosphate-ammonium sulphate (Leunaphos)	20·0	20·0	20·0	—	—	—	36·0	93	—
Monoammonium phosphate (Ammo-Phos A)[30]	11·0	48·0	48·0	—	1·5	0·5	6·0	55	—
Monammonium phosphate-ammonium nitrate[30]	28·0	14·0	14·0	—	0·5	—	2·0	61	—
Monammonium phosphate-ammonium sulphate (Ammo-Phos B)[30]	16·0	20·0	20·0	—	0·5	—	38·5	86	—
Urea-superphosphate (Phosphazote)	7·0	([25])	15·0	—	([25])	([25])	([25])	13	—
NITROGEN-POTASSIUM MATERIALS									
Potassium ammonium chloride (Potazote)	13·0	—	—	22·0	—	—	—	70	—
Potassium chloride-ammonium nitrate[31]	16·0	—	—	28·0	—	—	—	29	—
Potassium nitrate (nitrate of potash)	13·0	—	—	44·0	0·5	0·5	—	—	23
Sodium potassium nitrate[32]	15·0	—	—	15·0	—	—	—	—	26
PHOSPHATE-POTASSIUM MATERIALS									
Monopotassium phosphate, pure	—	52·2	52·2	34·6	—	—	—	0	0
Potassium metaphosphate	—	55·0	55·0	38·0	0·5	—	—	0	0
NITROGEN-PHOSPHATE-POTASSIUM MATERIALS									
Ammonium potassium phosphate	5·5	54·0	54·0	18·5	—	—	—	([18])	—
Nitrophoska[33]	12·0	12·5	12·0	21·5	9·0	1·5	3·0	([18])	—

See footnotes on next page.

— None, or present in quantity less than 0·5 per cent.

[1] "Equivalent acidity" is the number of parts by weight of calcium carbonate ($CaCO_3$) required to neutralize the acidity resulting from the use of 100 parts of the fertilizer material. For example, ammonium sulphate has an equivalent acidity of 110. It would therefore take 110 kilogrammes of calcium carbonate to neutralize the acidity developed in the soil by the use of 100 kilogrammes of ammonium sulphate as fertilizer.

[2] "Equivalent basicity" is the number of parts by weight of calcium carbonate ($CaCO_3$) that corresponds in acid-neutralizing power to 100 parts of the fertilizer material. For example, calcium cyanamide has an equivalent basicity of 63. This indicates that 100 kilograms of calcium cyanamide applied to the soil would be equivalent in its capacity to 63 kilogrammes of calcium carbonate for neutralizing soil acidity.

[3] Ammonium hydroxide, aqua ammonia, ammonia liquor, "B" liquor.

[4] Muriate of ammonia, sal-ammoniac.

[5] Nitrogen solution, Spensol, aqueous solution of ammonium nitrate and ammonia.

[6] Leunasaltpetre, Montansaltpetre, Leuna-Montan. A French product of similar character, called "le sulfonitrate d'ammoniaque," contains 25·5 per cent nitrogen.

[7] Cyanamid, lime-nitrogen, kalkstickstoff, Nitrolime.

[8] A-N-L, kalkammonsaltpetre, calcium ammonium nitrate. Mixture of ammonium nitrate with either precipitated calcium carbonate, ground high-calcium limestone, or ground dolomitic limestone. Another grade of Cal-Nitro contains 16 per cent nitrogen and about 27 per cent CaO. Also, similar products are marketed under the names of Nitro-Chalk (15·5 per cent nitrogen and 27 per cent CaO) and Peti So (17 per cent nitrogen.)

[9] The natural product from Chile is commonly called Chilean nitrate or Chile saltpetre.

[10] Fertilizer grade of urea manufactured in the United States; the material produced at present contains a small quantity of dolomite as a conditioning agent. Technical-grade urea is guaranteed to contain 46 per cent nitrogen; it has an equivalent acidity of 83 kilogrammes of calcium carbonate per 100 kilogrammes of material.

[11] No figures for composition of phosphate rocks are given because responses of crops to dressings of ground phosphate rocks are so extremely variable, depending on soil, climate, kind of crop, and type of rock. Analysis figures would be entirely misleading.

[12] Thomas slag, Thomas phosphate, Thomas meal.

[13] Basic.

[14] Defluorinated phosphate, fused phosphate rock, fused tricalcium phosphate, alpha phosphate.

[15] Precipitated phosphate, Fertiphos.

[16] Thermo-Phos, calcium magnesium phosphate.

[17] Sulphate content of phosphoric acid made by the sulphuric acid process. Electric furnace phosphoric acid contains very little sulphate.

[18] Acidic.

[19] Made by heating phosphate rock with silica and soda ash. Other products made with silica and soda ash or sodium sulphate include Silico Phosphate, Basi-phosphate, Supra-phosphate, and Supertomasyna.

[20] Made by heating phosphate rock with soda slag from desulphurization of pig iron.

[21] Superphosphate, normal superphosphate, standard superphosphate, acid phosphate.

[22] Triple superphosphate, treble superphosphate, multiple superphosphate, concentrated superphosphate.

[23] Sulphate content of material made with phosphoric acid manufactured by the sulphuric acid process. Material made with electric furnace phosphoric acid contains very little sulphate.

[24] The composition of this material varies widely.

[25] No data.

[26] Fermentation of sugar-cane molasses.

[27] Patentkali, Kalimag, Kali-magnesia, double manure salts.

[28] Ammoniated superphosphate is the product obtained when superphosphate is treated with ammonia or with a solution containing free ammonia and other forms of nitrogen dissolved therein.

[29] Material manufactured in the Netherlands. A similar material containing about 16 per cent each of nitrogen and P_2O_5 was produced in Germany under the name of Stickstoffkalkphosphat.

[30] Material made with phosphoric acid manufactured by the sulphuric acid process. Material made with electric furnace phosphoric acid has higher purity.

[31] Potassium ammonium nitrate, Kaliammonsaltpetre. A French product of similar character, called "Nitropotasse," containing 16·5 per cent nitrogen and 25 per cent K_2O.

[32] Nitrate of soda-potash, Nitrapo.

[33] Several grades and types of Nitrophoska have been marketed. The analysis given is that of the material produced in Germany of the beginning of World War II. Many other grades and types of mixtures containing nitrogen, P_2O_5 and K_2O are marketed under various trade names in the different countries.

efficiency. Solid fertilizers cannot be uniformly distributed in the field if they cake or become sticky, if they undergo segregation on handling, or if their drillability (rate of flow) is poor for any reason, such as fineness of particle size.

Many fertilizer materials absorb moisture from the air, which causes them, as well as the mixtures in which they are included, to become sticky. Serious caking may occur when fertilizers are subjected to pressure, as in large piles or high stacks, or when moisture is lost because of changes in atmospheric conditions. Caking of mixed fertilizers may also be caused by chemical reactions among the ingredient materials. These conditions greatly increase the difficulty of handling the fertilizer and of distributing it uniformly in the field.

Owing to variations in the specific gravity, and especially in the particle size of the ingredients, a mixed fertilizer may segregate when it is agitated in shipping or in the process of application. A mixture applied to one section of a field may then differ considerably in composition from that applied to another.

The drillability or rate of flow of a fertilizer is at its best when the particles are dry, uniform in size, spherical in shape, and of such a size as to minimize the cohesive forces between them.

Poor physical condition of fertilizers can usually be largely or completely overcome by one or more of the following expedients:

(1) Regulation of the initial moisture content; (2) proper curing to ensure completion of chemical reactions before shipment; (3) use of the right kind and quantity of conditioning agent to hinder coalescence of the individual particles; (4) granulation of the fertilizer or, with mixtures, use of ingredients having uniform and relatively large particle size; (5) shipment in moisture-resistant packages; (6) protection from extremes of atmospheric temperature and humidity; and (7) storage in low stacks or piles.

Granulation of fertilizers, whereby the particles are converted into spheroids of nearly uniform size and composition, promotes good physical condition. A number of fertilizer materials, including ammonium nitrate, ammonium phosphate, calcium cyanamide, calcium nitrate, sodium nitrate, and superphosphate, are marketed wholly or partly in granular form. Granulation of mixed fertilizers is a common practice in the United Kingdom and is receiving much attention in other countries.

Fertilizer Grades and Ratios

The grade of a fertilizer designates its percentage content of plant nutrients, generally in the following order: total nitrogen (N), avail-

Table 5. APPROXIMATE COMPOSITION OF NATURAL ORGANIC FERTILIZER MATERIALS[1]

Material	Total nitrogen (N)	Total phosphoric acid (P_2O_5)	Total potash (K_2O)	Total lime (CaO)	Total magnesia (MgO)	Total sulphate (SO_3)	Equivalent acidity[2]	Equivalent basicity[3]
	(........................	....	Per cent	....	....	...........)		
ANIMAL BY-PRODUCTS								
Blood, dried	13·0	2·0	1·0	0·5	—	—	23	—
Bone ash	—	35·0	—	46·0	1·0	0·5	—	(5)
Bone, dissolved, (bone superphosphate)	2·0	[4]15·0	—	25·5	0·5	27·0	0	0
Bone black, spent	0·5	35·0	—	46·0	1·0	—	—	(5)
Bone meal, raw	4·0	22·5	—	31·5	1·0	0·5	—	20
Bone meal, steamed	2·5	25·0	—	33·0	0·5	0·5	—	25
Crab scrap, blue	4·5	3·5	0·5	28·5	1·0	1·0	—	(5)
Fish scrap, acidulated	6·0	6·0	—	8·5	0·5	4·5	5	—
Fish scrap or meal, dried	9·5	7·0	—	8·5	0·5	0·5	5	—
Hoof and horn meal	14·0	1·0	(6)	2·5	—	2·0	(7)	—
Lobster scrap	4·5	3·5	(6)	21·0	1·5	0·5	—	(5)
Locusts, dried	10·0	1·5	0·5	0·5	(6)	(6)	(7)	—
Shrimp bran or waste	7·0	4·0	1·0	7·5	—	(6)	(7)	—
Starfish meal	5·0	1·0	1·0	24·5	2·5	0·5	—	(5)
Tankage, animal	7·0	10·0	0·5	15·5	0·5	1·0	—	13
Tankage, process	9·0	0·5	—	0·5	—	1·0	16	—
Whale guano or tankage	9·5	6·5	(6)	9·0	0·5	(6)	4	—
Wool waste	3·5	0·5	2·0	0·5	—	(6)	(6)	(6)
EXCRETA								
Guano, bat	8·5	5·0	1·5	7·5	0·5	2·0	(7)	—
Guano, Peruvian	13·0	12·0	2·5	11·0	1·0	3·5	13	—
Manure, cattle, dried	2·0	1·5	2·0	4·0	1·0	0·5	—	(5)
Manure, horse, dried	2·0	1·5	1·5	1·5	1·0	0·5	—	(5)
Manure, goat, dried	1·5	1·5	3·0	2·0	(6)	(6)	—	22
Manure, poultry, dried	5·0	3·0	1·5	4·0	1·0	2·0	(7)	—
Manure, sheep, dried	2·0	1·5	3·0	5·0	2·0	1·5	—	(5)
Sewage sludge, dried	2·0	2·0	—	2·5	0·5	0·5	(7)	—
Sewage sludge, activated	6·0	3·0	0·5	2·5	1·5	1·0	10	—

PLANT RESIDUES								
Ash, cottonseed hull	—	5·5	27·0	9·5	5·0	2·5	—	55
Ash, sunflower stalk, U.S.S.R. ..	—	2·5	36·0	18·5	(6)	—	—	(5)
Ash, tobacco	—	3·0	23·0	22·0	6·0	5·5	—	(5)
Ash, wood, commercial	—	2·0	5·0	32·5	3·5	1·0	—	(5)
Castor pomace	5·5	1·5	1·5	0·5	0·5	—	6	—
Cocoa meal	4·0	2·0	2·5	0·5	1·0	—	(6)	(6)
Cocoa shell meal	2·5	1·0	2·0	1·5	0·5	—	—	2
Cottonseed meal	7·0	3·0	2·0	0·5	0·5	0·5	10	—
Garbage tankage	2·5	3·0	1·0	4·5	0·5	1·0	—	7
Hempseed meal	5·0	2·5	1·0	2·0	0·5	—	(6)	(6)
Kelp, Pacific, dried	2·5	1·5	15·0	1·5	1·0	2·5	(6)	(6)
Linseed meal	5·5	2·0	1·5	0·5	1·0	1·0	(6)	(6)
Mowrah meal	2·5	1·0	2·5	—	0·5	(6)	(6)	(6)
Groundnut meal	7·0	1·5	1·5	0·5	0·5	1·5	(7)	—
Peat, moisture-free	2·0	—	—	1·0	0·5	0·5	(8)	(8)
Rapeseed meal	5·5	2·5	1·5	1·0	0·5	0·5	(6)	(6)
Seaweed, air-dry	1·5	0·5	2·0	3·0	1·0	3·5	(6)	(6)
Soot	1·5	0·5	0·5	3·0	1·0	6·0	(6)	(6)
Soybean meal	7·0	1·5	2·5	0·5	0·5	0·5	(7)	—
Tobacco stems	2·0	0·5	6·0	5·0	0·5	1·0	—	25
Tung meal	5·0	1·5	1·5	0·5	1·0	(6)	(7)	—

— None, or present in quantity less than 0·5 per cent.

[1] The organic fertilizer materials usually vary widely in composition. The figures given are average or typical analyses.

[2] "Equivalent acidity" is the number of parts of calcium carbonate ($CaCO_3$) required to neutralize the soil acidity resulting from the use of 100 parts of the fertilizer material

[3] "Equivalent basicity" is the number of parts of calcium carbonate ($CaCO_3$) that corresponds in acid-neutralizing power to 100 parts of the fertilizer material.

[4] Contains about 12 per cent available P_2O_5.

[5] Basic.

[6] No data.

[7] Acidic.

[8] Some peats are acidic and others basic.

able phosphoric acid (P_2O_5), and water-soluble potash (K_2O). The nutrients other than these three are customarily omitted from the grade designation, although in some countries the amount per bag of such nutrient elements as copper, manganese, cobalt, and molybdenum added to mixed fertilizers is also stated. A 5-10-5 fertilizer contains 5 per cent total nitrogen, 10 per cent available phosphoric acid, and 5 per cent soluble potash, and has a nutrient ratio of 1:2:1. The 8-16-8 and 10-20-10 grades also have a 1:2:1 ratio, but the total nutrient contents are 32 per cent and 40 per cent as against 20 per cent in a 5-10-5 fertilizer. Those containing only two of the major nutrients are designated, for example, as 0-14-14 or 16-20-0. With single-nutrient fertilizers the grade is commonly designated by a prefix to the name of the material, for example, 50-per cent potassium chloride or 48 per cent superphosphate. The first of these designations means that the material contains 50 per cent of soluble potash; the second, that it contains 48 per cent of available phosphoric acid. In some cases such a value may designate the percentage of phosphate or potassium compound present. The grade of a fertilizer, especially a mixed fertilizer, is usually stated in whole numbers, and in some countries the use of fractional grade designations is prohibited by law. Some countries—the United Kingdom, for instance—require a declaration of the exact plant-nutrient content within narrowly defined limits of error to cover inevitable irregularities in mixing, sampling, and analysing.

Standardization of fertilizer grades and ratios and their restriction to the minimum number needed to meet the specific soil conditions and crop requirements of the individual country or area are highly desirable. This makes for economy in the manufacture, storage, and handling of the fertilizers and simplifies the farmer's problem in choosing the proper fertilizers for his particular circumstances.

Fertilizer Materials

Nitrogen materials. The principal nitrogenous materials are ammonium sulphate, ammonium nitrate and its mixtures, sodium nitrate, calcium cyanamide, and calcium nitrate. With the exception of cyanamide these materials are widely used in mixed fertilizers as well as for direct application to the soil. Because calcium cyanamide contains a high percentage of active lime, it can be used in most types of mixed fertilizers in only limited quantities. Ammonium nitrate and its mixtures, and also sodium nitrate, find extensive use as side-dressing and top-dressing materials, while ammonium sulphate is preferred for mixed fertilizers because of its superior physical properties.

Large quantities of anhydrous ammonia, ammonia solution, and

especially ammonium nitrate-ammonia solution and urea-ammonia liquor are used in the manufacture of mixed fertilizers, chiefly in the United States. Such use requires the presence of superphosphate in the mixture, whereby the free ammonia is fixed principally as ammonium phosphate and a portion of the phosphorus is converted into water-insoluble forms. Care must be exercised in the use of free ammonia in this way because of the danger of decreasing the availability of the phosphate. This process has very limited application in countries where solubility in water is the criterion of phosphorus availability in mixed and compound fertilizers.

With proper precautions, as mentioned elsewhere in this monograph, the various nitrogen materials can be used interchangeably on most crops. On lowland rice, however, ammonium sulphate or urea is preferred. As a fertilizer, calcium cyanamide is incorporated with the soil before seeding or planting; heavy applications aid in controlling weed seeds and certain soil-borne diseases. Calcium cyanamide is also used as an herbicide and as a defoliant for cotton to facilitate the gathering of the crop. Though toxic when applied as a dust to the foliage of broad-leaved plants, cyanamide can be safely used as a top-dressing for grass. Urea is a useful fertilizer material because of its high nitrogen content (42 to 46 per cent). It is also an important industrial chemical, and in the United States it has proved to be a good source of nitrogen in feed for ruminants, when used in limited quantity. In contact with combustible materials, nitrates present fire hazards. This is especially true of ammonium nitrate, and under unusual conditions ammonium nitrate fires might involve an explosion risk.

With the exception of ammonium sulphate, the commonly used solid chemical nitrogen materials, especially ammonium nitrate and calcium nitrate, absorb moisture more or less readily from the atmosphere. All chemical nitrogen fertilizers are readily soluble in water and are easily leached from the soil or capable of rapid conversion in the soil into easily leachable forms.

Phosphate materials. Ordinary superphosphate, by far the most common phosphate fertilizer material, is manufactured in nearly all countries that use substantial quantities of fertilizer. Although a relatively low-analysis material—only 16 to 20% P_2O_5—it is satisfactory for use in mixed fertilizers as well as for direct application to the soil. It is a suitable source of phosphorus for all crops and for nearly all soils except those that contain active iron and aluminium compounds.

Double superphosphate differs from ordinary superphosphate in that it contains a much higher percentage of phosphorus and little or no sulphur. Its manufacture requires more expensive equipment,

and the production cost per unit of phosphorus is somewhat higher than that of the ordinary material under comparable conditions. Nevertheless, double superphosphate offers much promise as a low-cost source of phosphorus for areas far removed from fertilizer manufacturing plants. Many other promising high-analysis phosphatic fertilizers are being developed.[1]

Basic slag, a by-product of the steel industry, is a very important fertilizer in some countries. Owing to its high basicity it is used almost entirely for direct application. The phosphorus of basic slag, like that of dicalcium phosphate, defluorinated phosphate rock, phosphate rock-magnesium silicate glass, and Rhenania phosphate, is practically insoluble when a small portion of water is added, but it is mostly soluble in contact with large amounts of water containing carbon dioxide, as in moist soil. The availability of these materials is estimated by their solubility in either ammonium citrate or citric acid. For the most part they appear to be less satisfactory than the water-soluble phosphates for crops on alkaline soils. On acid soils basic slag is also a useful fertilizer because of its lime content.

Though much ground raw phosphate rock is used directly as fertilizer in some countries, its effectiveness varies greatly with the type of material, including fineness of grinding, and with different crops, soils, and farming systems. The phosphorus of such material is generally utilized best by applying it to legumes in crop rotations on acid soils of medium to heavy texture that are well supplied with organic matter. The availability of the phosphorus may be increased when the phosphate rock is used in composts. In order to get the maximum benefit, the raw phosphate rock must often be used at a rate considerably in excess of that at which the chemically processed phosphates prove effective. The effect of mineral phosphate dressings may not be very spectacular in the first year, but the benefits become more evident in later years. This generalization needs qualification, however, because under certain conditions good responses to phosphate rock have been obtained in the first year. For instance, in the wetter regions of the United Kingdom, spectacular results have been obtained on acid soils in the first year by the use of North African phosphate rock on swedes (turnips). In many instances the increases in yields were almost identical with those obtained from dressings of superphosphate containing an equal amount of phosphorus. Before using phosphate rock, the farmer should get the advice of agricultural authorities as to its probable merits under his specific conditions, because different types of mineral phosphate may vary considerably in their efficiency as sources of phosphorus when used for direct

[1] See footnote 1, page 46.

application. For instance, crystalline apatite is of very low value for direct application.

Potassium materials.[1] Potassium chloride (muriate of potash) supplies most of the fertilizer potash. For nearly all crops this material is as satisfactory as other forms of potassium. A notable exception is tobacco, the quality of which is impaired by too much chloride. Beets and white potatoes are also sensitive to large quantities of chloride. Potassium sulphate is preferred for these and for citrus crops.

Multiple-nutrient materials. Monoammonium phosphate and its mixture with ammonium sulphate are the most widely used of the individual chemical fertilizer materials that contain more than one nutrient element. The ammonium phosphate products have excellent physical properties and high nutrient content. Ammoniated superphosphate is produced mostly in mixture with other materials by treating mixed fertilizers containing superphosphates, chiefly with ammonia solutions of ammonium nitrate or urea or with anhydrous ammonia. Diammonium phosphate—an even more concentrated material—may become important.

Natural organic materials. The natural organic materials, most of which are low in plant nutrients, vary widely in physical characteristics, chemical composition, and nutrient quality. When used in sufficient quantity, they generally improve the physical condition of mixed fertilizers by reducing caking and hardening. Though phosphorus and potassium are the principal elements of value in bone products and plant ashes, respectively, most of the natural organic materials are valued chiefly for their content of nitrogen, especially the water-insoluble nitrogen (usually amounting to more than 65 per cent of the total nitrogen), which is considered to be less subject to leaching from the soil and to be available to plants over a longer period of time than the nitrogen of the water-soluble chemical materials. There is increasing evidence, however, that these supposed advantages of water-insoluble nitrogen are of no very great practical importance. Furthermore, the unit cost of natural organic nitrogen in many countries is very much higher than that of chemical nitrogen.

Other materials. Aside from limestone, the phosphate materials supply most of the *calcium* in fertilizers. The most important phosphate fertilizer, because it is the one most widely used, is ordinary superphosphate, which furnishes calcium in the forms of monocalcium phosphate and calcium sulphate. Basic slag is also an important source of calcium and, in addition, double superphosphate, bone products, calcium cyanamide, and ammonium nitrate-calcium carbonate mixtures supply some of this plant-nutrient element.

[1]See footnote 1, page 46.

Dolomitic limestone is a major source of *magnesium*. Other important sources include basic slag, certain potassium fertilizers, magnesium oxide, and magnesium sulphate. In certain areas with soils on which dolomitic limestone acts slowly, soluble salts of magnesium, such as magnesium sulphate, are sometimes mixed with the commonly used fertilizers.

The ordinary superphosphate and the ammonium sulphate products supply most of the *sulphur* in fertilizers. Elemental sulphur (brimstone) and gypsum (calcium sulphate) are used as amendments on alkaline soils.

Borax ($Na_2B_4O_7.10H_2O$) furnishes nearly all the fertilizer *boron*; more than 90 per cent of the world's supply is produced in the United States.

Copper, *iron*, *manganese*, and *zinc* are used mostly in the form of the sulphate salts.

Advantage of high-analysis materials. During the past 50 years, important developments in the chemical fertilizer industries have resulted in production of materials of higher plant-nutrient content. For example, the ordinary superphosphate produced in the United States now averages about 19·5 per cent available P_2O_5 as compared with only 14·5 in 1900. Potassium chloride containing 60 per cent or more of K_2O is now produced in large quantity, while the maximum potash content of the material marketed before 1920 seldom exceeded 50 per cent. Other high-analysis materials now manufactured on a large scale include double superphosphate (43 to 49 per cent available P_2O_5), the ammonium phosphates (59 to 74 per cent nitrogen and P_2O_5 together), ammonium nitrate (33 per cent nitrogen), and urea (42 to 46 per cent nitrogen).

As compared with the low-analysis products, the concentrated materials have an advantage in the cost of bagging, handling, and transportation per unit of plant nutrients. This advantage increases with the distance from the point of production. As a result, despite the frequently higher cost of manufacture, the concentrated materials can be supplied to farmers in many localities and countries at unit costs considerably less than those of the low-analysis products.

Mixed Fertilizers

Mixed fertilizers are those which are combined and distributed in the field in one operation.

Equally good or better agronomic results can be obtained by applying fertilizer materials separately, but the use of mixed fertilizers has these advantages: (1) Fewer man-hours are required to apply a mixture than to apply its various materials separately—an important factor in areas where farm labour is scarce and expensive; (2) mixtures

may have better physical condition and are more easily applied than many separate fertilizer materials; (3) the residual acidity of fertilizers can be conveniently and effectively controlled by the use of a proper quantity of dolomitic liming material in the mixtures; (4) plant nutrients required in small amounts can be applied more evenly by being incorporated in mixed fertilizers; and (5) if a proper mixture is used for the particular soil type and crop, less care on the part of the farmer is needed to assure the right proportion of plant nutrients in the soil than when individual materials are applied separately.

The disadvantages of mixed fertilizers are: (1) their use does not permit application of individual nutrients at specific times which may best suit the needs of the crop; (2) since fertilizer materials are not easily recognized in mixtures, the farmer usually has no way of prejudging the quality of the plant nutrients in relation to his specific conditions of crop and soil; (3) the total concentration of plant nutrients in a mixture is usually much less than that in the materials from which it is made, so that for a given weight of nutrients more fertilizer must be handled and transported in the form of a mixture than in the ingredient materials; (4) the unit cost of plant nutrients in mixtures is usually higher than in the ingredient materials; and (5) farmers are often led to use some mixture without careful study of their exact needs, thus using too little of some nutrients and more than necessary of others.

The *formula* of a mixed fertilizer shows the kind and quantity of each material contained therein. Knowing the formula, one is able to judge the type and quality of the nutrients and their suitability for specific soils and crops, and to determine roughly the quantity of sand and other inert material used in its preparation. Sometimes the formulas of certain mixtures are freely disclosed by the manufacturers. Such mixtures are known as *open formula* fertilizers, while the term *closed formula* is applied to mixtures with undisclosed formulas. In some countries use of closed formulas is prohibited.

Fillers and conditioners. In making a mixture of a specified grade, it is seldom practicable to obtain the exact quantities of nitrogen, phosphoric acid, and potash desired in a ton by the use of only the fertilizer materials themselves. In order that the mixture will contain the quantities of the nutrients specified by the grade, it is usually necessary, therefore, to add material containing neither nitrogen, phosphoric acid, nor potash. Such material is called "filler." It may serve only as a makeweight to balance out the formula to an even grade, or it may serve also (1) as a conditioning agent to reduce caking and improve drillability, an especially important factor in the preparation of mixtures from high-analysis materials; (2) as a cor-

rective of the residual acidity of the fertilizer; and (3) as a source of other nutrient elements. These are legitimate uses of filler within the limits of conditions prevailing in the area of intended use. Indiscriminate addition of filler solely as a makeweight unnecessarily increases the cost of plant nutrients to the farmer.

If the mixture does not contain a natural organic fertilizer material, it is often advisable to add a conditioning agent. Although some inorganic substances, such as dolomitic limestone, are suitable for this purpose, use is made chiefly of vegetable products and wastes which usually contain small percentages of plant nutrients. Addition of limestone or dolomite to mixed fertilizers to correct residual acidity is justified for those areas where farm use of calcium and magnesium liming materials has not been adequately established. But more than this unjustifiably increases the cost through lower analysis.

The average nutrient concentration of mixed fertilizers has not kept pace, in general, with that of the materials from which they are made. This means that, as a rule, mixed fertilizers unfortunately now have more added filler than formerly. Many mixtures contain 25 per cent or more of makeweight filler, most of which could be eliminated with a corresponding increase in the grade of the fertilizer and a reduction in handling, transportation, and distribution costs per unit of plant nutrients and consequently in farm costs. The seriousness of the problem is indicated by the situation in the United States, where, according to recent estimates, about 50 per cent of the filler used in mixed fertilizers is technically and agronomically unnecessary. Elimination of this useless material would reduce the annual national fertilizer bill by at about 2 per cent. Solution of the filler problem is not simple. It involves, among other things, the highly important but time-consuming task of educating the farmer to buy fertilizers on the basis of unit plant-nutrient cost rather than on the price-per-ton basis.

Incompatibilities in mixed fertilizers. The preparation of satisfactory mixed fertilizers requires detailed knowledge of the chemical and physical characteristics of individual materials and of their behaviour in mixtures under different conditions of storage, transportation, and use, as well as under varying circumstances of atmospheric temperature and humidity.

Chemical reactions causing actual loss of plant nutrients or their conversion into less available forms may occur in mixed fertilizers. For example, calcium cyanamide, basic slag, quicklime, slaked lime, and other highly basic materials cause loss of nitrogen from ammonium salts. Except in limited quantities these materials, as well as anhydrous and aqueous ammonia, also decrease the availability of the phosphoric acid in superphosphates. Other materials, notably am-

monium nitrate, calcium nitrate, and urea, may impart poor physical condition to mixed fertilizers because they are highly soluble in the moisture of the mixtures and they readily absorb atmospheric moisture. Such materials can be utilized in only limited quantities unless the other ingredients are low in moisture and the mixture is well protected from the atmosphere. Still other materials, ammonium sulphate, for example, may cause serious caking in improperly cured mixtures.

Home-mixed fertilizers. Some fertilizer materials can be bought and mixed satisfactorily on the farm without the use of special equipment. Home mixing may be more economical than the use of factory-made mixtures. Especially in communities distant from the sources of supply, considerable saving may be made by purchasing the high-analysis materials and mixing them in a local farm co-operative. This practice also has definite educational values: it encourages study and experimentation to ascertain what mixtures are best adapted to particular soils and crops; it serves as an incentive toward acquiring knowledge of different fertilizer materials and their values; and it assures precise knowledge of ingredients and the ability to duplicate mixtures that may prove particularly effective.

Where farm labour is scarce and expensive, however, farm mixing may be impracticable and uneconomical. Farm mixtures are likely to have poorer physical condition and drillability than factory-made mixtures unless used very shortly after preparation. If fertilizers are needed only in small quantities and if suitable ones are available at fair prices, it is usually more convenient to buy commercial mixtures.

Liming Materials

Liming materials are used to neutralize soil acidity, to improve the physical properties of soil, and to increase the calcium and magnesium content of the soil.

Limestone. The term *limestone* refers to rocks consisting chiefly of calcium carbonate ($CaCO_3$) or calcium carbonate and magnesium carbonate ($MgCO_3$). When the magnesium carbonate content is significant, the material is called *dolomitic limestone*. Although the total neutralizing effect of a certain quantity of any limestone is the same whether it is coarsely ground or finely ground, the reaction of the fine material in the soil is much more rapid. The degree of grinding varies greatly. In localities where limestone is abundant, the tendency is to grind less fine and make heavier applications. On the other hand, when transportation costs are high or rapid action is desired with a limited rate of application, finer grinding is recommended.

Limestone ground so that 50 per cent passes a 0·25 millimetre mesh sieve or 30 per cent passes a 0·15 millimetre mesh sieve provides a

satisfactory product for general farm use, but more finely ground material that will pass a 0·15 millimetre mesh sieve is also being produced. Its cost per ton is usually 50 to 100 per cent greater than the coarser grade.

Limestone as mined varies greatly in purity or neutralizing value. To rank as a fair to good grade, the neutralizing value should be equal to at least 80 per cent of that of pure calcium carbonate.

Because of its magnesium content, dolomitic limestone is preferred on soils deficient in this plant nutrient. It also has another advantage. There is far less danger of overliming with this material because, as the acidity is corrected, the rate of its solution is much lower than that of high calcium limestone and especially of burned or hydrated lime.

Marl. Marl is loose, friable calcium carbonate intermixed with varying amounts of clay, organic matter, and usually some magnesium carbonate. The magnesium content, however, is usually so low that marl is not a good source of this element. Marl deposits vary in thickness from a few centimetres to several metres and usually occur in swamps or lake beds. The neutralizing value of marl varies from less than 50 per cent to more than 90 per cent of that of pure calcium carbonate. As mined, marl is usually high in moisture content, and drying is necessary before it is spread on the land. Because it does not require grinding, its use should find favour where grinding machinery is lacking.

Burned and hydrated lime. When limestone ($CaCO_3$ and $MgCO_3$) is heated above 600° C., carbon dioxide is driven off and calcium and magnesium oxides (CaO and MgO), known as burned lime, remain. On adding water, the hydrated forms ($Ca(OH)_2$) and ($Mg(OH)_2$) result. Burned and hydrated lime are used in making mortar and in liming soils. As liming agents they are quick acting, but because of their caustic nature they should be applied a week or two in advance of planting. These materials need to be spread carefully and evenly, since an excess may make other nutrients unavailable.

By-product liming materials. In a number of industrial processes, by-product liming materials suitable for soil treatment are produced. The principal forms are dust from marble works, mine tailings, precipitated calcium carbonate from sugar mills, sludge from paper mills, and waste from gas works and acetylene plants. The last-named usually contain toxic substances which, however, soon escape or are made innocuous on drying or mixing with soil.

Wood ashes. Fresh, unleached hardwood ashes usually contain about 30 to 40 per cent lime (CaO), 4 to 6 per cent potash (K_2O), considerable amounts of silica (SiO_2), and lesser amounts of other mineral elements commonly present in wood. Wood ashes may have a

neutralizing value equal to that of high-grade limestone. In addition, they supply some phosphate and notable amounts of potassium.

Calcium silicate slag. Blast-furnace slag, a by-product of the pig-iron industry, contains chiefly calcium silicate ($CaSiO_3$). When this material is pulverized, its neutralizing effect on acid soils may be 80 per cent or more of that of pure calcium carbonate. Besides calcium, it contains significant quantities of other nutrient elements. Some by-product calcium silicate slags from the manufacture of elemental phosphorus are also excellent liming materials. Basic slag, a by-product of the manufacture of steel from high-phosphorus iron ores, is valued chiefly for its content of available phosphorus, but it also contains considerable calcium silicate. In soil-neutralizing value, basic slag is equivalent to two-thirds or more of its weight of calcium carbonate.

Materials for Ameliorating Alkali Soils

Soils which now contain or have previously contained high concentration of salts are sometimes infertile and require corrective treatment for one or more of the following undesirable conditions: presence of salts in amounts which retard or prevent plant growth; high alkalinity or high acidity; bad physical condition; high water table. The excess salts can be removed by washing the soil if water of good quality is available and if drainage can be established. The various conditions ranging from high alkalinity to high acidity are usually corrected by application of sulphur, sulphur plus gypsum, gypsum, gypsum plus lime, or lime alone. But other materials may also be used. Thus, ammonium sulphate resembles sulphur in reducing alkalinity; sulphuric acid, iron sulphate, and aluminum sulphate have the same effect but are usually too costly. Marl, slaked lime, and limestone are used to correct soil acidity. An unfavourable physical condition of the soil can sometimes be corrected by the establishment of grass or some other vegetation or by a period of bare fallow. A high water table is corrected by diverting the inflow of water, installing drains, pumping from wells, or establishing suitable vegetation, such as some kinds of eucalyptus. In the Punjab, in areas where irrigation water of good quality is plentiful, alkali soils containing calcium carbonate have been successfully reclaimed by rotating rice with berseem (*Trifolium alexandrinum*), which is ploughed under as green manure. The roots of the rice plant evolve large quantities of carbon dioxide, which brings the calcium of the carbonate into solution. The dissolved calcium converts the sodium clay into a calcium clay, and the berseem provides the soil with much-needed nitrogen and organic matter (see also the section on *Soil Amendments on Alkali Soils* in Chapter V).

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V

USE OF FERTILIZERS, MANURES, AND SOIL AMENDMENTS

Factors Affecting the Use of Fertilizers and Manures

The efficient use of fertilizers and manures involves soils and their management, crops and their sequence, climate (including supply of moisture), systems of farming, and the farmer's profit. These factors may vary from one locality to another, from farm to farm, and even from field to field.

SOILS AND THEIR MANAGEMENT

Although crops differ in their needs for nutrient elements, their fertilizer requirements depend largely upon the soil. For example, nitrogen is used more commonly than phosphorus as a fertilizer for wheat in Europe, but in Australia the reverse is true because so many Australian soils are deficient in phosphorus.[1]

The differing fertilizer requirements of wheat on different soil types are demonstrated by the results obtained in Chile at thirteen experiment stations. At four of these stations marked increases in yield were secured with nitrogen; at another five, phosphorus was the most effective plant nutrient; at two other stations both nitrogen and phosphorus were needed. At two stations no significant increases were obtained with nitrogen, phosphorus, and potassium applied either singly or in combination. At one of these stations the yield of wheat is high, indicating high soil fertility, but at the other the yield is low. In the latter case, lack of response to fertilizer can be explained by the existence of other growth-limiting factors, probably lack of moisture aggravated by poor physical condition of the soil.

As indicated by the Chilean experience, within a limited region there may be many kinds of local soil types that differ appreciably in their plant-nutrient content and in other factors affecting soil productivity. In India, for example, nitrogen is the most common limiting plant-nutrient element. Some soils in the subcontinent of

[1] In Australia nitrogen may also be limiting. But, apart from stubble-sown oats and barley, it has been found uneconomic to apply nitrogen fertilizers where the nitrogen supply of the soil has been depleted by continued cereal cropping, because the soils require improvement in structure through the addition of organic matter and because increases in the available nitrogen level are attained at lower net cost by the use of peas and legumes, including herbage legumes used for pastures.

India, however, have greatest need for phosphates. Doubtless, as more nitrogen is used in this region, deficiencies of phosphorus, potassium, and other nutrients will become more apparent at the higher levels of productivity.

A number of methods can be used to assess the fertilizer requirements of different soils (see Chapter VIII for some of them), but the most reliable method is field experimentation. The knowledge gained by field trials on particular types of soil can be extended to individual farms and fields on similar soils by the use of soil maps and analyses and other techniques and by general experience with local soils. Although fertilizer practices vary with different soil types, past management of soils also has a great influence on these practices.

Soil management includes not only fertilizing, manuring, and crop rotation, but also cultural practices, drainage, irrigation and water conservation. Management of the soil may alter its properties to such an extent that two fields with the same type of soil, but under different management, may require very different fertilizer treatment (see photo No. 17).

For instance, one field has been used to grow cereal crops for many years, without manure or fertilizer. An adjacent field of the same acid soil type has been used over the same period of years under a system of management which included a rotation of legumes and cereal crops and the use of manure, fertilizer, and lime. When the time comes to devise an identical cropping system for the two fields with a suitable fertilizer programme, it is obvious that treatments for the first field will differ from those for the second. The first field will in all probability need more lime and fertilizers than the second.

Again, two fields are of the same soil type, with similar slope and drainage. One has been well managed to prevent loss of soil by erosion; the other through mismanagement has lost a good portion of its original surface soil. A much more rigorous programme of soil management and fertilizer dressings is required on the eroded field to restore it to usefulness than on the field which has been consistently well handled.

CROP DIFFERENCES

Experience and research show that different crops differ in the amounts of several plant nutrients that they need and in their sensitivity to deficiencies. Some crops are better "foragers" for the plant nutrients already in the soil and respond less to these nutrients in fertilizers than other crops on the same soil; some crops, also, are shallow rooted, while others take nutrients from a considerable depth. Recognition of these specific requirements is important to the efficient

use of fertilizers. The brief statements that conclude this section indicate a few of the relative differences among some common crops when grown in soils moderately deficient in available nitrogen, phosphorus, and potassium, but under favourable conditions of climate, including rainfall.

In general, the grasses and cereals show greater response to nitrogen than to the other plant nutrients. Such crops as maize and sugar cane produce high yields per hectare and require large amounts of nitrogen (see photo No. 18). Common applications to these crops are 50 to 100 kilogrammes of nitrogen per hectare, and sugar cane may receive much more when all other growth factors are favourable (see photo No. 19). Grass meadows and pastures respond to heavy applications of nitrogen if sufficient soil moisture is available for optimum growth. Under most situations, however, grasses should be grown in mixtures with the legumes; this practice improves the quality of the forage, reduces the need for nitrogen fertilizer, and, if the deeply rooted sorts are used, aids in the maintenance of soil structure. The successful growing of these legumes often reduces the need for nitrogen but increases the need for the minerals, especially phosphorus, potassium, and calcium. In some areas some of the nutrients needed by plants in small quantities must also be supplied. For instance, parts of South Australia require applications of copper, molybdenum, and zinc for good growth of legumes and parts of the United States require applications of boron for lucerne. In the United Kingdom and in some other European countries, good results have been obtained with heavy nitrogen applications to pastures containing legumes. With proper cutting and grazing, both the legumes and the grasses thrive under this treatment.

Excessive application of nitrogen in fertilizer or manure to cereal crops such as wheat, barley, rice, and oats often causes lodging, which leads to decreased yields. These crops ordinarily receive not more than 20 to 40 kilogrammes of nitrogen to the hectare.[1] Heavy nitrogen application to a cereal crop serving as a nurse crop for grass and legume seedings often increases the shading and reduces the stand and growth of the seedings.

In contrast to the grasses and cereals, legume hay crops need little if any nitrogen from fertilizers, except perhaps a little when sown, but require potash, phosphate, and often calcium. Under favourable soil conditions, they obtain their nitrogen from the abundant supplies in the air if the seed is inoculated with the proper bacteria.

[1] In the Union of South Africa in the summer rainfall area, only half this rate can be used with safety, because with high nitrogen applications considerable "burning" occurs in periods of drought.

Photo No. 17. Accelerated erosion of sloping lands through overgrazing and lack of the necessary fertilizer. Note the difference between the well-used land on the left of the line fence and the ill-used land on the right.

Photo by courtesy of the Tennessee Valley Authority, U.S.A.

Photo No. 18. *Response of maize to nitrogen. Experiment conducted by North Carolina Agricultural Experiment Station in* 1946 *on a commercial farm near Princeton, North Carolina, U.S.A., on a Norfolk fine sandy loam which was limed in the autumn of* 1943. *This is a deep yellow Podzolic soil of low fertility, developed from unconsolidated layers of sandy loam, sand, and sandy clay of the Coastal Plain. The soil in* 1946 *was medium acid (pH* 5·9). *Triple superphosphate at* 190 *kilogrammes* (90 *kg.* P_2O_5) *and muriate of potash at* 146 *kilogrammes* (90 *kg.* K_2O) *per hectare were side-placed at planting time by means of the fertilizer-distributor and maize-planter combination. The healthy looking maize on the right received in addition* 110 *kilogrammes of ammonium sulphate* (22 *kg. N) per hectare at planting time and* 1,100 *kilogrammes of nitrate of soda* (180 *kg. N) per hectare as a side-dressing when the plants were* 75 *centimetres high. The per-hectare yield of the nitrogen-fertilized maize on the right was* 7 *metric tons of grain, while that of the nitrogen-starved maize on the left was only* 1·5 *metric tons.*

Photo by B. A. Krantz.

In general, root crops and legumes respond more to phosphorus and potassium than to nitrogen fertilizers, although this depends a great deal on the soil type; for instance, on muck or sandy soils potassium is often needed in substantial amounts. Truck crops—tomatoes[1] and lettuce in particular—also respond well to phosphate fertilizers. Ordinarily the amount of phosphate required by most legume and root crops ranges between 40 and 80 kilogrammes of available P_2O_5 per hectare. Potatoes and vegetable crops under intensive production may respond well to twice these amounts where other factors are favourable.

Crops that are especially responsive to potassium fertilizers are white and sweet potatoes, sugar beets, mangolds, tobacco, tomatoes,[2] cotton, maize, and legumes.[2] Grass crops and cereals other than maize are generally less responsive to potassium than to nitrogen and phosphorus fertilizer. But, again, this varies with the soil type. In Europe and in certain sections of the United States, potatoes often receive as much as 150 to 200 kilogrammes of K_2O per hectare. In contrast, maize and cotton ordinarily receive only 30 to 60 kilogrammes per hectare. Tomatoes and tobacco receive intermediate amounts.

Crop responses to animal manure. Unfortunately there is not enough manure available on most farms to permit an adequate application to each field each year. In a rotation, emphasis should be given to the use of manure on the more valuable crops which respond well to applications of plant nutrients and to improved soil structure and also on those with a long growing season. The plant-nutrient content of manure naturally depends on the kind and amount of feeding stuffs and litter and on the way the manure is made and used. Manure usually supplies useful quantities of nitrogen, potassium, and phosphorus. For root crops, experiments in the United Kingdom show that smaller dressings of potassium and phosphorus fertilizers are needed on manured land than on similar land without manure. With ordinary applications, however, there appears to be no need to cut down the nitrogen fertilizer on the manured land for crops requiring large amounts of nitrogen, because the joint chemical and physical effects of manure enable the crops to respond profitably to more nitrogen than is afforded by the manure.

Sugar beets, potatoes, fodder beets, turnips, cabbage, maize, and

[1] This applies also to tomatoes under glass in temperate humid zones where outdoor growing of the crop is impossible because of weather conditions.

[2] In the Union of South Africa practically no response to potassium fertilizers has been found, although animal manure containing fair amounts of potassium is commonly used for potatoes, sugar cane, tobacco, and certain vegetables and fruits. Cotton and maize definitely do not require potassium fertilizers.

oilseeds respond particularly well to manure. Legumes and cereals generally respond less. The legumes can utilize atmospheric nitrogen, and the cereals have a lower potassium and phosphorus requirement than many other crops. Liquid manure is used well on such crops as fodder beets, potatoes, turnips, cabbage, rutabaga, rape, maize, and spring cereals. It is a poor fertilizer for legumes.

The principle of diminishing returns holds with manure as with fertilizers; generally the most efficient use of manure is obtained with medium rates of application. This is particularly true of the first crop grown after manuring. Applications of 10 to 20 tons per hectare are most commonly used, but much higher rates are sometimes used in intensive vegetable cropping. In establishing stands of legume seedings, a rate of 5 to 10 tons per hectare is sufficient. The opportunities for increasing agricultural efficiency through better care and use of manure can scarcely be over-emphasized. On millions of farms these opportunities can be realized with little new capital investment.

Crop rotations and rates of application. Where systematic crop rotations are followed, the place of the crop in the rotation often determines whether nitrogen fertilizer is required. If maize or small grains follow legumes, for example, they may obtain all or most of their nitrogen needs from the decomposing roots and residues of the legume crops; on the other hand, if they are grown the second or third year after the leguminous crop, they may require a relatively large quantity of fertilizer nitrogen. However, if all other factors are favourable, maize usually responds to a side-dressing of nitrogen in mid-season, even following a legume, sometimes very markedly indeed.

If a crop in the rotation is heavily fertilized, there may be some phosphorus and potassium not used by that crop, and this residual material may help to meet the fertilizer requirements of the following crop. Residual effects are uncommon with chemical nitrogen fertilizer, however, because this form of nitrogen, if not used by the crop, is readily leached out of the soil.

The use of animal manure affects the rates of fertilizer applications. When manure is applied, lesser quantities of fertilizer may be needed.

The amount of fertilizer used for various crops is also influenced to a large extent by the hectare value of the crop. The crop of highest hectare value generally receives the bulk of the fertilizer. During World War II and in the succeeding years of food shortage, some countries took steps to encourage the use of fertilizer on food crops at the expense of other crops. While the practice of giving preferential treatment to high-value crops is sound, there is sometimes a tendency

to use such large amounts of fertilizer on these crops as to be'aps economic, while the other crops on the farm are slighted. This is especially true on farms where potatoes, tobacco, vegetables, or similar intensive crops are grown on the same fields year after year. On a few farms in the eastern United States and in the United Kingdom, for example, large amounts of phosphorus and potassium have accumulated in the soil from high annual applications made through the years. On these farms the amount of fertilizer now used on special crops is often higher than necessary. Uneconomic use of fertilizers results from too large applications, because the response of crops per unit of fertilizer applied diminishes as the quantity of fertilizer is increased beyond that needed for a fairly good crop. But too small amounts are also often uneconomic. In soils quite deficient in some nutrient, enough must be applied to provide normal growth; smaller amounts may be essentially wasted (see photo No. 20). The farmer's problem is to find the rate of fertilization that will provide the greatest net return rather than the greatest yield, considering the whole rotation of crops and the long-time productivity of the soil. The fertilization of crop rotations is further discussed in Chapter VI.

CLIMATE AND SOIL MOISTURE

Differences in soil moisture greatly modify fertilizer requirements. Generally, soils in dry regions are not so leached as those of humid regions, and contain more nutrients. Further, moisture supply in these regions is usually a greater limiting factor than the nutrient supply. But irrigation may change the fertilizer need completely. Under dry-farming, fertilizer application may not increase crop yields, but crops may respond wonderfully to nitrogen and phosphorus on the same soil under irrigation. In an experiment in the Anglo-Egyptian Sudan, an application of about 670 kilogrammes of ammonium sulphate per hectare increased the hectare yield of seed cotton by 744 kilogrammes when irrigation water was used at the normal rate, but by only 304 kilogrammes when irrigation water was used at half the normal rate. To utilize high fertility levels effectively in the soil, irrigated crops may respond to additional irrigation over those growing on soils of low or medium fertility. Also, abundant fertility reduces the water requirement of plants as compared to low fertility. Of course, only factors that inhibit normal growth—nutrient deficiency, drought, or disease—raise the water requirement of plants.

Similarly, in humid regions, control of run-off water through terraces may so improve soil moisture conditions that fertilizers will give good responses where they did not before. Other things being

equal, the more favourable the environmental conditions for producing high yields, the greater is the quantity of fertilizer that can be used to advantage. For instance, in Australia the standard application of superphosphate is approximately 100 kilogrammes per hectare (22 kg. P_2O_5). Applications tend to fall below this value for wheat, especially in the areas of lowest rainfall, and to rise above it to maximum dressings of approximately 250 kilogrammes per hectare in the case of sown pastures when the rainfall is sufficiently liberal.

Phosphates help to promote root development and encourage early maturity in crops. In some areas with a short growing season, and especially in those with a moist climate, phosphate fertilizers are used to hasten maturity of the crop. On the other hand, heavy applications of nitrogen encourage a heavy top growth and tend to delay ripening of crops, make the crop more susceptible to disease, and reduce the mineral content of the plant. For these reasons it may be necessary in a cool moist climate to limit the rate of nitrogen application. Certainly high amounts must not be used when the mineral elements are deficient.

SYSTEMS OF FARMING

The system of farming determines to a considerable extent the kinds of fertilizer that should be used and the rate of application. For one thing, fertilizer treatment of crops depends upon whether manure is used. When grown without manure, sugar beets in England require roughly equal amounts of nitrogen, phosphate, and potash; when abundant manure is used, the dressing of phosphate and potash can be reduced or eliminated. It is evident, then, that fertilizer practices on livestock farms should be somewhat different from those on farms where little or no livestock is kept and no manure is used. The fertilizer practices used by a market gardener growing his crops intensively must differ from those of a farmer growing similar crops extensively. The dry-land farmer in all probability uses fertilizers at a quite different rate of application than his neighbour on an irrigated farm, even though soil types of the farms are nearly identical.

FINANCIAL RETURNS

The most efficient fertilizer dressing is that which gives the maximum financial returns after allowing for the cost of the fertilizer and any additional costs resulting from the larger crops. But these calculations must be based on a period of years, possibly 5 to 10, not just on one year. It is often best, for example, to add the phosphate intended for lucerne at the time of seeding the previous cereal. The good effects of vigorous, well-fertilized legume hays may be realized

Photo No. 19. Experiments conducted in 1946 at Picton Estate of Ste. Madeleine Sugar Company, Ltd., Ste. Madeleine, Trinidad, on a tropical Red Podzolic soil. This is a very strongly acid (pH 4·7) silt clay with impeded drainage because of heavy texture. The soil is low in organic matter, nitrogen, and available phosphorus. The field on the left, which received the routine estate fertilizer application of 375 kilogrammes of ammonium sulphate (77 kg. N) per hectare, yielded 100 metric tons of sugar cane per hectare. The field on the right, treated with 750 kilogrammes of superphosphate (135 kg P_2O_5) and 1,000 kilogrammes of ammonium sulphate (205 kg. N) per hectare, yielded 137 metric tons. The picture was taken when the cane was 23 weeks old.

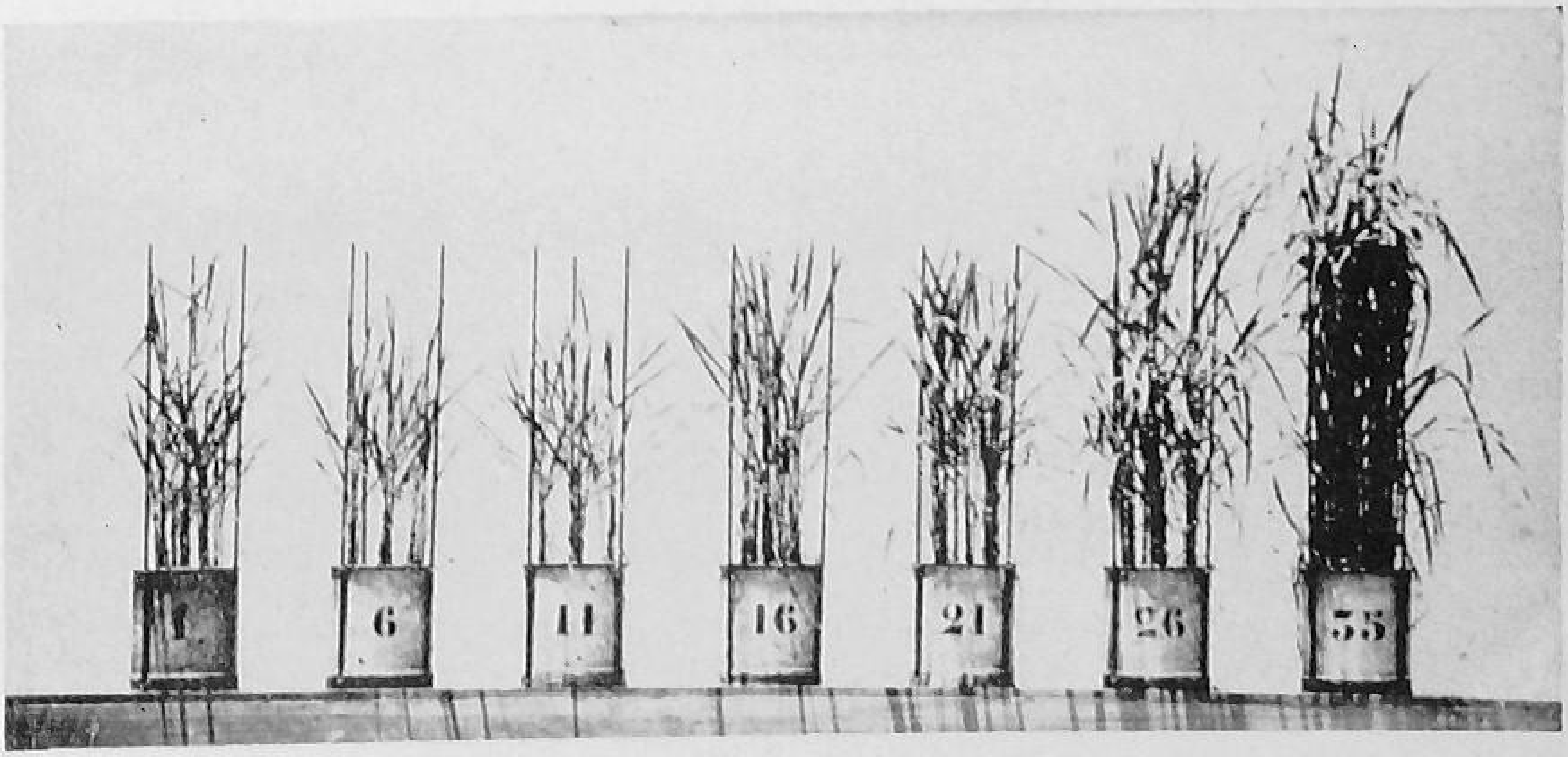
Photo by courtesy of F. Hardy.

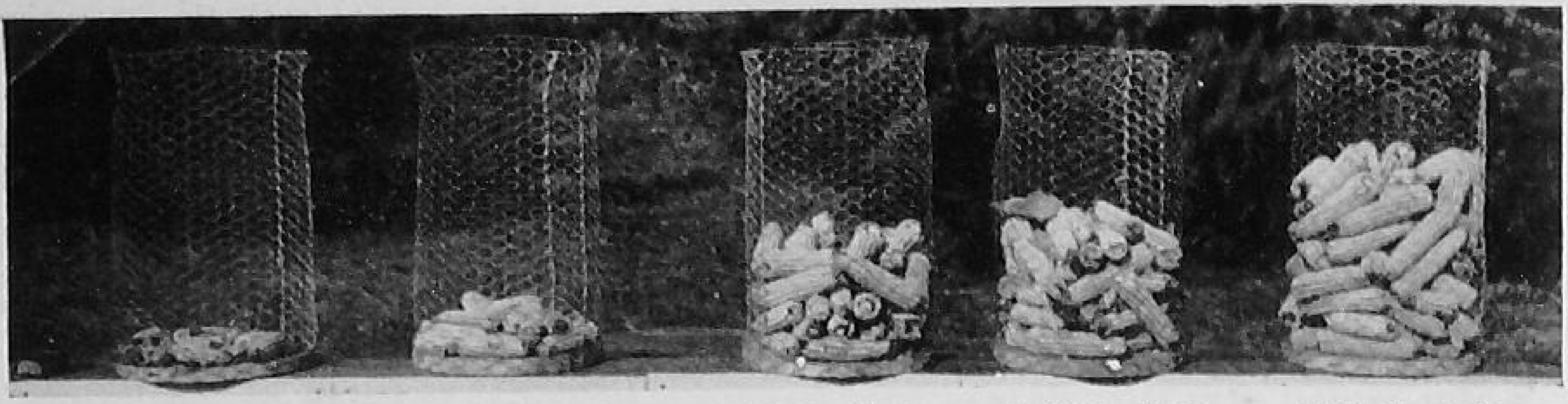
Photo No. 20. Response of rice to phosphate in pot experiments on soil from Nova-Iguassu, Brazil. The soil of Nova-Iguassu needs heavy applications of phosphate. Pot No. 1 on the left received no fertilizer; the others received lime, together with heavy applications of nitrogen and potash. Phosphate was applied in graduated amounts to the different pots. Satisfactory growth was obtained only with the heaviest application of phosphate (Pot No. 35 on the right). The yields were as follows:

Pot	6	11	16	21	26	35
Phosphate (P_2O_5) *kg./ha*	0	35	69	138	277	555
Yield, grammes per pot (dry weight)	*Lost*	*Lost*	49	69	87	166

The smaller applications of phosphate, therefore, were nearly useless. This is an example of phosphate fixation. Data of M. Laravia, A. L. du Cruz, C. del Negro. Mem. No. 5. Inst. de Chemice, Rio de Janeiro.

Photo by courtesy of T. F. do Amorim.



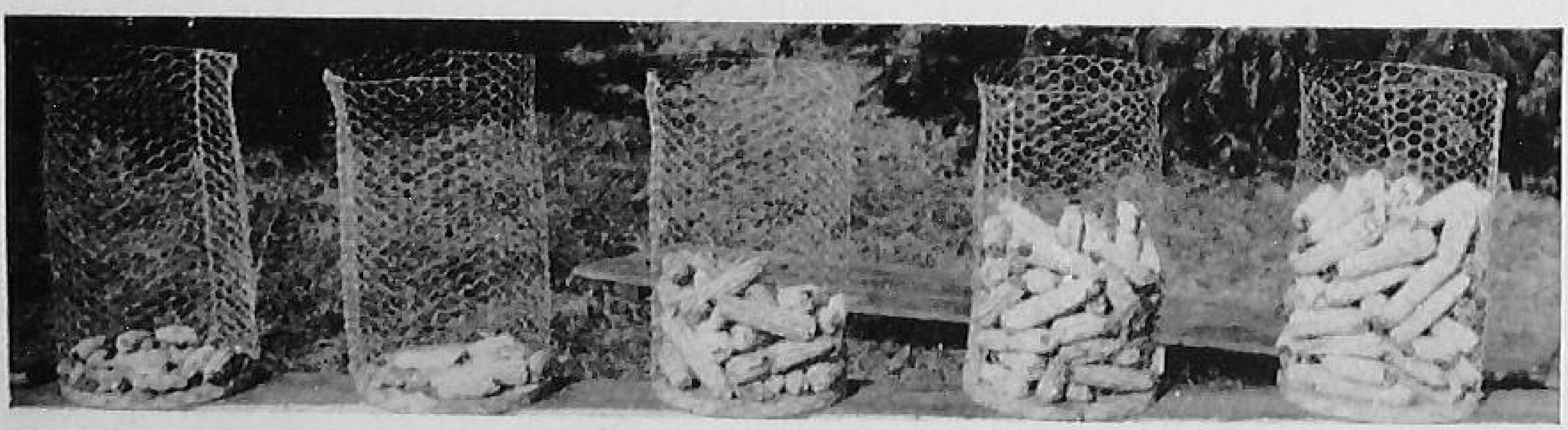


N P_2O_5 K_2O 0 0 0 | N P_2O_5 K_2O 0 70 70 | N P_2O_5 K_2O 70 70 70 | N P_2O_5 K_2O 100 70 70 | N P_2O_5 K_2O 100 70 70 and lime

Photo No. 21. Response of maize to nitrogen at different rates of application. Experiment conducted by Georgia Mountain Experiment Station in Georgia, U.S.A., on Hayesville clay loam—a Red Podzolic soil of medium acidity (pH 5·7), moderate depth, and low fertility. Nitrogen was applied as ammonium nitrate, phosphorus as triple superphosphate, and potassium as muriate of potash, but in the picture the rates of application of these fertilizers are expressed in kilogrammes of N, P_2O_5, and K_2O per hectare respectively. All of the phosphorus and potassium and one-third of the nitrogen was applied at planting and two-thirds of the nitrogen as a side-dressing when the maize was 35 days old. Previous to planting, 3 metric tons per hectare of dolomitic limestone was applied to one plot as indicated in the photo. The maize in each basket represents the yield from an area of 25 m². Note the increase in yield with increases of nitrogen application and the further increase when lime was applied.

Photos by Orien L. Brooks.

Photo No. 22. Response of maize to phosphorus at different rates of application. Experiment conducted by Georgia Mountain Experiment Station in Georgia, U.S.A., on Hayesville clay loam—a Red Podzolic soil of medium acidity (pH 5·7), moderate depth, and low fertility. Nitrogen was applied as ammonium nitrate, phosphorus as triple superphosphate, and potassium as muriate of potash, but in the picture the rates of application of these fertilizers are expressed in kilogrammes of N, P_2O_5, and K_2O per hectare respectively. All of the phosphorus and potassium and one-third of the nitrogen was applied at planting and two-thirds of the nitrogen as a side-dressing when the maize was 35 days old. Previous to planting, 3 metric tons per hectare of dolomitic limestone was applied to one plot, as indicated in the photo. The maize in each basket represents the yield from an area of 25 m². Note the increases in yield with increased phosphorus applications and the further increase when lime was applied.



N P_2O_5 K_2O 0 0 0 | N P_2O_5 K_2O 100 0 70 | N P_2O_5 K_2O 100 25 70 | N P_2O_5 K_2O 100 70 45 | N P_2O_5 K_2O 100 70 70 and lime

in subsequent crops, even 5 years after the fertilizer is used. Perhaps nothing is more important to effective use of fertilizers than for farmers to think of their practices in terms of the long-time effects, both direct and indirect, rather than in terms of the immediate results only.

Fertilizer use is to some extent influenced by the relationship between the price the farmer has to pay for the fertilizer and the price he receives for his produce.

In 1941 Crowther and Yates showed how a simple expression for the law of diminishing returns could be used to bring together the results of large numbers of field experiments of various designs so as to evaluate the average responses to standard fertilizer dressings under defined conditions. From these standard responses the net returns could be evaluated for different crops at various levels of fertilizer application. Optimal dressings could be related to the prices of crops and fertilizers or to other restrictions, such as shortage of supplies and the special needs of various kinds of soil. These principles were applied in the war-time rationing of phosphorus and potassium fertilizers in the United Kingdom. Once the average responses have been determined from a series of field experiments, the same principles can be applied in drawing up a manuring programme for a single farm or district.

Field Experimentation

Because the responses to fertilizers and manures are so variable, depending on soil, crop (and even different varieties of the same crop), season, and other factors, a large number of experiments on a variety of soil types, with different crops and in different years, are required to make sound fertilizer recommendations. Experiments should be conducted to indicate what fertilizers and animal manures should be used and in what quantities. It should also be noted that under certain combinations of soil and climatic conditions crops do not respond to fertilizers. The response to fertilizers and manures is sometimes very little with light applications (see photo No. 20) and it also falls off as the total amount of dressing is increased beyond the optimum. Therefore, in field trials to determine rates of application, some very heavy dressings should be applied to reach and exceed the optimum level (see photos Nos. 21, 22 and 23). From the results of such experiments it is possible to advise farmers as to rates of application, but the fertilizer and manure rates recommended will not necessarily give the highest yield per hectare, because the farmer is primarily interested in net return (excess of output over input) rather than highest yield.

With a large number of field experiments it is possible to obtain representative averages of crop responses to different levels of fertilizer application. If the soil types do not differ too widely in their requirements for fertilizer and manure, average crop responses to these treatments can be determined on a district or even a country basis, and generalized recommendations on fertilizer and manure dressings can be made. Such information is of value in formulating policies for the efficient use of fertilizers for districts and countries. This type of appraisal was made in the United Kingdom at the beginning of World War II, and formed a basis for the policy of fertilizer use in that country during the war and after. The results of thousands of experiments conducted in the United Kingdom, Denmark, southern Sweden, and East Prussia were used in the investigation and some important conclusions were reached. Some of the more important were:

(1) For root crops, smaller phosphate and potash dressings are required on manured land, but no reduction should be made in the nitrogen applications.

(2) Considerable increases in agricultural production in the United Kingdom are possible from the greater use of nitrogen, especially on cereals.

(3) In allocating the short supplies of potash among crops, potatoes should receive preference.

For a country which has to import a considerable portion of its phosphate and all of its potash, but which has its own well-developed nitrogen industry, these findings were of great value and permitted the formulation of policies for the more efficient use of fertilizers in the general national plan of increased agricultural production.

Yet, usually, fertilizer recommendations need to be based upon the individual soil types, rather than upon a district as a whole. In most places, even the local soil types differ widely in their requirements for supporting optimum growth.

Time and Method of Application

Obviously it would be impossible to attempt specific recommendations on the use of fertilizers for the many thousands of individual soil types in the world and for the large number of crops grown under a great variety of conditions. For this reason the preceding discussion is limited to the more important factors that determine the selection of fertilizers and their rates of application. But, once it has been decided which materials are to be used on which field and crops, the important problem of determining how and when the job should be done to obtain the best results still remains. It is not enough to

apply the right kind and amount of fertilizer, manure, or soil amendment. If these materials are to be used most efficiently, they must also be applied at the right time and in the right way. This is particularly important when a short supply of fertilizers must be used to obtain optimum increases in crop yields.

APPLICATION OF COMMERCIAL FERTILIZERS[1]

The two general methods of applying fertilizers are broadcasting and localized placement. In broadcasting, the fertilizer is spread over the entire soil area to be fertilized. This is usually done immediately before planting the crop. But it is sometimes done before the land is ploughed or while the crop is growing; this last method is usually referred to as "broadcast top-dressing."

With certain commercial fertilizers, experiments have shown that a given amount may produce a greater increase in crop yield when placed in the soil in narrow bands near the seed than when broadcast. With other fertilizers, or under other conditions, however, the two methods may be equally satisfactory, or broadcasting may be preferable. It is evident, then, that the answer to how and when different fertilizers should be used is not simple. A number of factors determine the results obtained, among them the type of soil, previous management of the land, the crop to be grown, the method of planting, and the kind and amount of fertilizer used. The farmer must also consider the labour cost of applying the fertilizer in different ways and the machinery available for doing the job.

The main objective in broadcasting is to distribute the fertilizer evenly and usually to mix it with from 5 to 10 centimetres of the surface soil by subsequent cultivation. Broadcasting is done with various types of spreaders, or by hand. In general, a low-down gravity-type spreader, which distributes more evenly, is preferred to one based on the centrifugal principle. In some countries, however, for instance South Australia, the centrifugal spreader is preferred because of the lower cost of application.

In many areas, including most European countries, broadcasting is the only method extensively used. It is a satisfactory method where nitrogen fertilizers are used and where heavy applications are made to maintain a high fertility level for intensive crop production.

Localized placement means placing the fertilizer either in bands or local areas along the planted row, often in a definite space relation-

[1] No distinction has been made between chemical and natural organic types of fertilizers in the discussion of methods and time of application because the underlying principles for both types are similar. It should be noted, however, that usually no high concentration of soluble salts develops when natural organic fertilizers are added to the soil.

ship to the seed or plant. This is not a new method. Early in the seventeenth century some American Indians put fish in the hills with seeds of maize, and Chinese farmers have long observed the practice of placing oilcake meal at the side of each hill of sugar cane and beside each row of cotton and tobacco. It is common practice in China to plant seed mixed with dry manure in open furrows.

In Egypt, nitrogen fertilizer is applied in pinches at the base of each pair of cotton plants. In France, solutions of fertilizers are injected into the soil around fruit trees at the outer perimeter of the branches. Australia, the Netherlands East Indies, New Zealand, the Punjab, and the United Kingdom have also used localized placement to advantage. It is in the United States, however, that this method of applying chemical fertilizer has received the greatest attention. A National Joint Committee on Fertilizer Application was organized in the United States in 1925, with representatives from public and industrial organizations. The committee has sponsored and suggested a great deal of research, and many recommendations based on this research may prove useful in other countries.[1] They should first, however, be tried out under local conditions. For instance, on potato experiments conducted in the United Kingdom, no better results were obtained with localized placement of fertilizer by machine than with the standard method of broadcasting fertilizers over the land after ridging and immediately before planting whole potato tubers. The standard British method automatically secures very good fertilizer placement. On the other hand, in the United States, where cut sets are often planted by machines working largely on flat land, localized placement of fertilizers by machines is strongly advocated and has proved advantageous. Good results with localized placement for potatoes have also been obtained in Australia.

Localized placement of fertilizers is often done at the time of seeding the crop with the use of a combination seeder and fertilizer distributor. When proper machinery is available, it can save labour and make more efficient use of small amounts of phosphate, potash, or mixed fertilizer. Machines are not absolutely necessary, however. In many countries it is practicable to place the fertilizer by hand with a dibble or hoe, or by simple animal-drawn machinery like the double-wing plough-ridger or cultivator shovel.

When fertilizers are placed in bands or nests near the plants, the roots of the young plants are assured an adequate supply of nutrients. This promotes a more rapid early growth, which makes it possible

[1] For recommendations of the National Joint Committee on Fertilizer Application covering a great range of crops, the reader is referred to *Methods of Applying Fertilizer* (revised November 1948), published by the National Fertilizer Association, 616 Investment Building, Washington 5, D.C., U.S.A.

with row crops to cultivate earlier and to have better weed control. Moreover, the loss of phosphorus and potassium through "fixation" is less than when the fertilizer is applied broadcast. Furthermore, since phosphates penetrate slowly into the soil, they often fail to reach the roots in sufficient quantity if they are applied at the surface. Localized placement makes available a greater portion of the nutrients added.

The greatest hazard of localized application of chemical fertilizers is that germination may sometimes be hindered or the young plant damaged by an excessive concentration of soluble salts if the materials are put near the seed or plant. Even surface broadcasting of chemical fertilizer may injure sensitive crops, if during a seed-bed ridging operation, considerable amounts of fertilizer are brought into the seed zone. When localized applications were first introduced, considerable difficulty arose because improperly designed machinery placed too much fertilizer where it would touch the seed. Much experimental work has been done on this problem since about 1925, and factors causing the damage are now understood. Injury is greatest in dry sandy soils, and chemical fertilizers vary considerably in their effect on the soluble salt content of the soil solution. Nitrogen and potassium fertilizers increase the salt content of the soil solution more than phosphate fertilizers.

In general, localized application of fertilizers in narrow bands at moderate rates is most effective for the more widely spaced row crops. The best position for the band is a few centimetres to one or both sides of the row and a little below the level of the seed or crown. Placing the fertilizer directly above the seed or in the furrow, or mixing the fertilizer with soil immediately around the seed, is generally hazardous with large amounts of fertilizer, although crops vary considerably in their susceptibility to damage from fertilizer salts.

Uniform distribution of fertilizers is important with both broadcast and localized methods of application, and particularly with the latter. Uneven distribution may result in salt damage to some plants and insufficient fertilization of others.

As an indication of the effectiveness of localized placement of fertilizer under suitable conditions, a comparison is made in Table 6 of the increases in yields obtained with some crops in the United States by the broadcast and localized methods of application.

Hill and row placement. In the United States, where many crops such as maize, tobacco, tomatoes, and certain other vegetable crops are spaced at a distance as great as a metre in rows which are one or more metres apart, hill placement is often practised. The fertilizer is usually applied at the time of planting by means of a fertilizer

attachment on the planter, but of course this operation can be done by hand. The fertilizer is distributed in bands about 15 to 20 centimetres in length and 2·5 centimetres in width on one or both sides of the hill. The lateral distance from the seed is usually 2 to 7 centimetres and the depth about 2 to 10 centimetres below the surface. This, however, varies with the crop grown and the amount of fertilizer applied. Heavier applications should be in longer bands and be farther away from the seed or transplant.

Table 6. COMPARISON OF BROADCAST AND LOCALIZED METHODS OF FERTILIZER APPLICATION

Location and soil type	Year	Crop	Fertilizer composition	Fertilizer rates	Yields: No fertilizer	Yields: Broadcast method	Yields: Localized placement
				kg/ha	Metric ton/hectare		
Ohio	1928	Maize (Grain)	4–12–4	560	2·0	2·4	4·5
Indiana .. .. Brookston silt loam[1]	1930	Maize (Grain)	4–10–6	134			3·6
				560	2·5	3·1	
Maryland		Potatoes	7– 6–5	1,120	(2)	0·3	4·0
Western Washington Sultan silt loam[3]	1946	Cucumbers	10–20–20	448	14·6	22·4	44·8
Western Washington Sultan silt loam[3]		Sweet maize	5–15–10	1,120	17·5	16·8	20·2
Western Washington Puget silt clay[4]	1943	Spinach	10–20–20	448	3·8	5·4	9·1
Virginia .. .. Sassafras loam[5]	1935	Lima beans (green unshelled)	4–10–8	1,120	3·3	4·3	5·5
Manhattan, Kansas Geary silt loam[7]	[6]1927–29	Wheat (Grain)	0–16–0	196	1·5	2·1	2·5

[1] Deep, weakly acid, or nearly neutral (pH 6·1-7·3) soil, highly productive when drained, developed on calcareous glacial drift under poorly drained conditions, changing to temperate forest (Humic-glei soil).
[2] No figures for the yield on the check plot are available; only the increases in yield due to fertilizer treatment are presented.
[3] Deep, strongly acid (pH 4·8-5·5) soil, moderately productive owing to restricted drainage and acidity, developed under temperate forest from mixed alluvium on level relief (Brown Podzolic soil).
[4] Deep, acid (pH 5·1-6·0) soil, moderately productive when drained, consisting of mixed alluvium with level relief (Alluvial soil).
[5] Deep, very strongly acid (pH 4·5-5·0) soil, moderately fertile when first cultivated but less fertile later. Productivity affected by acidity and soil texture. Developed under temperate forest on unconsolidated sands and sandy clays with nearly level relief (Grey Brown Podzolic soil).
[6] Four-year average.
[7] Deep, moderately acid (pH 5·6-6·5) soil, highly productive except in drier years, developed under grass from loess with undulating to rolling relief (Prairie, but transitional to Chernozem).

When the seed is drilled close together or the plants are placed rather closely in the row, the fertilizer is put in continuous uniform bands on one or both sides of the row, in the same relative position to the seed or transplant as indicated for hill placement. This method of application is known as row placement and is used with such crops

as maize,[1] cotton, tobacco, sugar beets, potatoes, and many vegetable crops (see photo No. 24). Somewhat higher rates of application are possible with row placement than with hill placement.

For applying small amounts of fertilizers, hill or row placement is usually most efficient. However, as the rate of application increases, the effectiveness of this method as compared with other methods commonly diminishes except for soils that fix phosphorus very much, like many of the red soils of the tropics.

When rates of application heavier than 700 kilogrammes[2] per hectare are used, as, for instance, in fertilizing potatoes and maize, the additional quantity should be applied some time before seeding, either by broadcasting it before ploughing or by dropping it on the bottom of the furrow while ploughing. Good results have been obtained in the United States on well-drained and well-limed soils by applying a part of the large quantity of fertilizer during the preparation of the seed-bed and the remainder at seeding or planting time.

Drill placement. Drill placement is essentially a row placement in which the fertilizer, together with the seed, is applied in narrow rows with a combination seed and fertilizer drill. The spouts through which the fertilizer and seed are distributed are ordinarily 15 to 23 centimetres apart.

With rates of application of phosphates and mixed fertilizers[3] up to 400 kilogrammes per hectare, this method is excellent for fertilizing small grains and some other close-growing crops that tolerate a small amount of fertilizer in contact with the seed. This method is used successfully with small grains in a number of countries; virtually the whole of the Australian wheat crop is sown with superphosphate by means of the combine drill. When the rate of application is stepped up to higher levels, it becomes necessary to apply part of it in some other manner and at a different time. On the other hand, poor stands and reduced yields may result if drill placement of fertilizers is used with salt-sensitive crops such as peas or beans. If these crops are grown in close-drilled rows, the fertilizer and seed may be drilled independently in the same direction or at right angles, requiring two trips over the ground to apply the fertilizer and drill the seed.

Plough-sole placement. With the plough-sole method the fertilizer is placed in a continuous band on the bottom of the furrow in the

[1] In the Union of South Africa, drilling seed and fertilizer in one operation is the usual method for planting maize, but this frequently leads to some setback in periods of drought.

[2] Refers to grades containing a total of 20 to 30 per cent nitrogen, phosphoric acid, and potash.

[3] Refers to grades containing a total of 20 to 30 per cent nitrogen, phosphoric acid, and potash. Calcium cyanamide damages most crops when drilled in contact with the seed.

process of ploughing. Each band is covered as the next furrow is turned. No attempt is made to plant the crop in any particular location with regard to the plough-sole bands.

This method has been advocated recently in the United States in areas where the few surface centimetres of soil become quite dry during the growing season, and especially with soils having a heavy clay pan a little below the plough-sole. By the deeper placement, the fertilizer is in moist soil where the roots are concentrated, and it remains more available to plants during dry seasons. Like other placement methods it should result in less fixation of phosphorus and potassium than when the fertilizers are broadcast. The plough-sole method is an efficient way to apply quantities of fertilizer too large for safe row or hill applications.

Combination of methods. A considerable quantity of fertilizer in the plough-sole, broadcast and ploughed under, or broadcast after ploughing, may still not supply enough fertilizer near the plant to provide for the best start and early growth of a crop. For row crops, therefore, it is usually better to apply at least a part of the fertilizer near the plants. Different methods of application may be desirable for a given crop if different fertilizers are applied separately, because localized placement is more important with phosphorus and potassium than with nitrogen fertilizers.

Top-dressing. It is not always desirable to apply all the fertilizer needed by a given crop before planting or at the time of planting, and additional fertilizer is often applied at some later date. This delayed application on the surface of the soil is referred to as a "top-dressing." If the crop is grown in wide rows, the delayed application can be made as a "side-dressing" in furrows near the row, opened with a hoe or cultivating implement.

Delayed applications of nitrogen fertilizer are most common. Vegetable crops, maize, grass crops, and sugar cane often receive top-dressings of nitrogen. Top-dressings of phosphate are ordinarily made only on crops that are used for hay or pasture and that occupy the land for several years. It is usually better to get phosphate down into the soil, if possible, with a disk or other tool, even on pastures.

Care must be taken in top-dressing that the fertilizer is not applied when the leaves of plants are wet, for it scorches the leaves. This injury is greater with nitrogen and potassium than with phosphate fertilizer.

Use on fruit and nut trees. Fruit and nut trees are a special case in that the method of application is often a compromise between broadcasting and localized placement; the fertilizer is broadcast under the trees to a distance of 30 to 60 centimetres beyond the spread of the

Photo No. 23. Response of maize to potassium at different rates of application. Experiment conducted by Georgia Mountain Experiment Station in Georgia, U.S.A., on Hayesville clay loam—a Red Podzolic neutral soil (pH 7·2), moderately deep and of medium fertility. Nitrogen was applied as ammonium nitrate, phosphorus as triple superphosphate, and potassium as muriate of potash, but in the picture the rates of application of these fertilizers are expressed in kilogrammes of N, P_2O_5, and K_2O per hectare respectively. All of the phosphorus and potassium and one-third of the nitrogen was applied at planting and two-thirds of the nitrogen as a side-dressing when the maize was 35 days old. Previous to planting, 3 metric tons per hectare of dolomitic limestone was applied to one plot, as indicated in the photo. The maize in each basket represents the yield from an area of 25 m^2. Note the increases in yield with increased potassium applications.

Photo by Orien L. Brooks.

Photo No. 24. Placement in cross section of seed-bed. Side placement of fertilizer for cotton (white areas right and left) in a narrow band 6 cm. each side and 5 cm. below the level of the seed (white area in centre).

Photo by G. A. Cumings.

Photo No. 25. Response of legumes to sulphur on Grey Wooded (Podzolic) soils. Experiment conducted at Breton Field, University of Alberta, Edmonton, Alberta, Canada. Sweet clover (Melilotus alba) *and red clover (Altaswede) mixture in a rotation of clover-wheat-oats-barley on loam soil of medium acidity (pH 6·0) and low natural fertility. The unfertilized plot on the left gave 1·0 metric tons of hay to the hectare; the fertilized plot on the right, 5·6 metric tons. The fertilized plot received for five years an annual application of 84 kilogrammes of ammonium sulphate per hectare; but in 1935, when this picture was taken, the application was changed to 90 kilogrammes per hectare, containing 19 kilogrammes of nitrogen and 21 kilogrammes of sulphur. Further experiments have shown that the good growth of clover is mainly due to sulphur. Grey Wooded (Podzolic) soils are somewhat deficient in sulphur, and clovers and other leguminous crops respond well to applications of this plant nutrient. Note the small quantity of fertilizer required to obtain a fivefold increase in yield.*

Photo by courtesy of F. A. Wyatt and J. D. Newton.

branches. On the other hand, when a cover or green-manure crop is grown between the trees, a large part of the fertilizer may be applied to this crop. In warm humid regions on very sandy soils the fertilizer application may be repeated several times during the season.

Starter solutions. At the time of transplanting to the field, starter solutions made by dissolving fertilizer salts in water are applied to young vegetable plants that have been grown in the greenhouse or cold frame. They are used in place of the water that is usually applied to help in establishing the plants. As only a small amount of fertilizer is used per plant, a starter solution is ordinarily a small proportion of the total fertilizer application. It takes the place of a small quantity of fertilizer placed near the plant.

The starter solution has two advantages: the nutrients reach all the plant roots immediately and the solution is sufficiently diluted that it does not inhibit root growth. There are two disadvantages: if watering is not a part of the regular operation, extra labour is necessary; and the fixation of phosphate may be greater, although the immediate effect somewhat compensates for the loss of phosphate.

Mixed fertilizers are generally used in making starter solutions. Such N-P_2O_5-K_2O ratios as 1-2-1 and 1-2-2 are satisfactory. Fertilizer materials that contain the maximum quantity of plant nutrients in relation to the total content of soluble salts are most desirable. Ammonium phosphate, ammoniated superphosphate, urea, potassium nitrate, and potassium sulphate are examples. The recommended concentrations vary inversely with the nitrogen content: from 1 kilogramme per 400 litres of water for fertilizers containing 25 per cent nitrogen to 10 kilogrammes per 400 litres of water for fertilizers containing 3 per cent nitrogen. When used on acid, sandy soils, the solution should be neutralized at least to pH 5.

GENERAL PRINCIPLES OF FERTILIZER APPLICATION

The best method and time of applying fertilizer depend on the kind and amount of fertilizer used, partly because individual fertilizer ingredients behave differently in the soil. Not all the fertilizer elements remain readily available or are utilized immediately by the crop to which they are applied. Efficient use of any fertilizer requires recognition of its properties as related to soil type and crop.

Phosphate. When water-soluble phosphates, such as superphosphate, are applied to soil, they combine with it to form new phosphate compounds that are less soluble and less available to crops. This process, known as "phosphate fixation," varies in degree. For instance, in soils of temperate grasslands (Chernozem), the phos-

phorus, although fixed, is nevertheless fairly available to plants, whereas in the mature soils of the hot humid tropics ("Red Loams" or Latosols) the phosphorus is so tenaciously fixed that plants can hardly get it. Because of fixation, crops may not use more than 10 per cent of phosphate fertilizers applied broadcast. The more thoroughly the superphosphate is mixed with the soil, the more thoroughly it is fixed and the less available it is to crops. If, on the other hand, the same quantity of superphosphate is placed in a narrow band, it touches a smaller proportion of the soil. The phosphate-fixing capacity of the soil immediately around the band is satisfied and more of the phosphate remains in an active form for use by the crop.

The greater benefit derived from localized application of superphosphates or of any of the water-soluble phosphate fertilizers is related to the phosphate-fixing power of the soil. The greater the fixing power, the greater is the relative value of localized application. Generally, soils high in clay content have greater fixing power than sandy soils. Strongly acid soils have a greater fixing power than soils that are nearly neutral or slightly alkaline. Acid soils should be limed if greatest efficiency is to be obtained from water-soluble phosphate fertilizers. More important, soils of tropical countries often have the greatest fixing power. Proceeding from the sub-Arctic to the equator, other things being equal, the phosphate-fixing power of the soil increases. Fortunately, the absolute amount of soluble phosphates needed in the soil during the growing season for good crop production decreases somewhat in the same progression. In the north, the growing season is very short, daylight is nearly continuous, and a high concentration of available nutrients is necessary.

Localized application is less necessary for ground rock phosphate to reduce fixation than for water-soluble phosphate. In fact, it is preferable to mix ground phosphate rock with the soil. The loss of soluble phosphate by fixation is not so important as getting the phosphate into solution. Thorough mixing of these materials with acid soil promotes more rapid solution and greater availability.

The best time to apply soluble phosphate fertilizers is usually immediately before or at the time of planting the crop.[1] If the fertilizer is applied several months before planting, more becomes fixed and less is available for the crop. Likewise, delayed applications or top-dressings of phosphate fertilizer are usually inefficient. The beneficial

[1] The other aspects of the farming system may, however, alter this. For example, it is often better to apply the phosphorus for grass and legume hays a year in advance, when the seedbed is being prepared for the cereal companion crop, than as a surface top-dressing later.

effect of phosphate on the early growth of the crop is lost if the application of fertilizer is delayed long after planting. In many cases this early benefit to the crop is much greater than the late-season effect. Moreover, for close-growing crops, a top-dressing must necessarily be applied broadcast on the surface. Because of fixation, the phosphate moves downward into the soil only very slowly with the soil water. Most of the phosphate applied, therefore, is retained within a few millimetres of the surface, and relatively few active plant roots have access to it. Top-dressing may be necessary to supplement the phosphate applied at the time of seeding permanent pastures and meadows, but it may be ineffective with poor stands of desirable plant species. Where the vegetation of permanent pastures consists mainly of weeds and poor grasses, it is better, if possible, to prepare a good seed-bed, drill the phosphate fertilizer needed,[1] and reseed with desirable legumes and grasses. When ploughing is not feasible, a single disk or other tool can be used to get the phosphates into the soil.

Potassium fertilizers also react with the soil to form new compounds that are less soluble and less available to plants than the potassium salts themselves. Fine clay particles in the soil fix potassium and the process is accelerated by wetting and drying. As with phosphate fixation, the greater the clay content of soils, the greater, generally, is the potassium fixation. But because potassium remains more soluble and mobile than phosphorus in the soil—even in clay soils—the problem of fixation is not so acute. Yet, generally, the principles of efficient phosphate use apply to potassium fertilizers to a lesser degree. Localized placement of potassium fertilizer is usually preferable to broadcast application with row crops. It is often preferable to apply potassium fertilizer at or just before planting. In this way the crop is provided with enough potassium during its early life to assure rapid growth and development. Often, however, this practice cannot be fitted into the system, and potassium can be applied to good advantage at other times.

Potassium fertilizers move down into the soil more easily and deeply than phosphates. Sandy soils in regions of heavy rainfall lose some potassium by leaching. Under these conditions two applications are best, one at or immediately before planting and the other as a delayed side- or top-dressing. Even in other soils, a side-dressing of potassium may be beneficial to cultivated crops, especially if insufficient potassium was applied at planting time. Top-dressings of potash

[1] In parts of Australia, however, no advantages have been shown on pastures as a result of drilling superphosphate as compared to broadcasting, apart from the more even distribution secured by drilling.

fertilizer are also effective on perennial crops like lucerne, especially on sandy soils.

Because the concentration of soluble salts in the soil is greater with potassium fertilizers than with phosphates, greater care must be taken in band or hill applications to prevent injury to young seedlings from direct contact with the fertilizer or from too large applications near the seed. The larger the application and the sandier the soil, the farther away the fertilizer should be from the seed. When large amounts of fertilizer are used, a distance of 5 or more centimetres from the seed may be necessary to protect the plants from injury.

Nitrogen. The main problem with nitrogen is to keep the fertilizer where it is wanted. Sooner or later, under conditions of good drainage and aeration, nitrogen added in fertilizers is converted to the nitrate form by soil micro-organisms. Nitrate nitrogen in the soil is easily soluble in water. It is not fixed by the soil, but is subject to movement with every movement of the water in the soil. A major problem is to prevent the nitrogen from being lost by leaching. This can be accomplished to a certain extent by using the ammonia forms, which are lightly absorbed by the soil in somewhat the same manner as potassium. Ammonia is changed to nitrates by soil micro-organisms, but under conditions of cool weather and band placement this process does not take place rapidly. Thus soils in humid regions should not be left bare during periods of leaching. A cover crop will take in the nitrate that would otherwise leach and hold it for the next crop.

Broadcast methods of applying nitrogen fertilizer at the time of planting are usually satisfactory, but localized placement of some of the nitrogen is often desirable for row crops. For example, maize grown in most parts of the United States is benefited by a relatively small amount of nitrogen applied in the row at the time of planting as a part of the fertilizer mixture. This provides available nitrogen for the young seedling and hastens early growth, especially when the soil is too cold for rapid nitrification. As with potash fertilizers, however, too large an application of nitrogen very near the seed may injure crops. For this reason the greater part of the nitrogen fertilizer is usually broadcast or drilled into the soil. As previously mentioned, the ploughing under of nitrogen may also be satisfactory, especially in regions of low summer rainfall, where the fertilizer may be more available if it is applied 10 to 20 centimetres deep than when applied on the surface.

It is desirable to apply a part of the fertilizer in mid-season as a top-dressing or, better still, as a side-dressing along the row or near the

hills, especially on sandy soils in regions of high summer rainfall. Even in fine-textured soils, maize and small grains often respond to a delayed top-dressing of nitrogen when the plants are five to six weeks old. A spring top-dressing of nitrogen invariably gives better results on autumn-planted cereals than a single application in the autumn. In the Indian subcontinent it has been found that better results are generally obtained with sugar cane if part of the nitrogen is applied at planting time and the remainder at earthing-up times. It is also found here that, for cotton grown under irrigation, a nitrogen top-dressing at the time of flowering is superior to applications at other times. In the irrigated sections of the United States satisfactory results are also obtained by supplying nitrogen fertilizers in irrigation water. The nitrogen becomes available to the crop as soon as the irrigation water enters the soil. On a limited scale in the United States nitrogen is also applied to the soil as anhydrous ammonia.

Mixed fertilizers. In the United States, Canada, the United Kingdom, and to a less extent in the continental European countries, a large part of the fertilizer is applied to the soil in the form of a mixture containing two or all three of the major plant nutrients. Since these mixed fertilizers are ordinarily high in phosphorus, the principles on time and method of application relating to phosphate fertilizers usually apply. Where the mixtures are used at planting time on crops like maize, it is often beneficial to follow with small, localized applications of nitrogen alone in mid-season. In general, localized applications of mixed fertilizers at the time of planting are advantageous; top-dressings are usually not recommended except for perennial crops. Mixed fertilizers high in nitrogen or potassium should not be used in direct contact with the seed unless experience with particular crop and soil conditions has shown that no damage follows.

Other elements. While nitrogen, phosphorus, and potassium are the so-called "big three" in fertilizer usage because they are so often deficient in soils of the temperate regions, they are by no means the only plant nutrients that are applied in fertilizers. Commercial fertilizers usually contain appreciable quantities of other plant nutrients. These may be present as carriers of impurities in the raw materials, like sulphur in ammonium sulphate or calcium and sulphur in ordinary superphosphate, which is a mixture of mono-calcium phosphate and calcium sulphate, or they may be a constituent part of the fertilizer.

Partly as a result of continued cropping and gradual change from relatively impure fertilizers and farm manures to more highly purified materials, deficiencies of iron, manganese, zinc, copper, boron,

molybdenum, calcium, magnesium, and sulphur frequently appear in crops as soils are built up in phosphorus, potash, and nitrogen. Of course, some soil types are naturally deficient in these plant-nutrient elements. Sufficient experience to diagnose and correct such deficiencies has only recently been gained. The first six of these nutrient elements are needed only in minute quantities, and special application methods, such as spraying or injection into the plant, are often used. In some cases, however, the deficiencies can be corrected by adding the salts of these elements to fertilizers in common use, as described in Chapter IV. When copper, zinc, manganese, boron, and molybdenum are applied in this manner, the quantities used should be kept within the narrow safe margins for each element.

Spray applications of nutrients required in small quantities have the advantage that the nutrients can be absorbed through the leaves and are effective almost immediately. Nutrient sprays can be combined with sprays used to control insects and plant diseases. Spraying, however, is temporary in its effect, and must be repeated several times during the season if the deficiency is severe. Some deficiencies, especially of shrubs and trees, are more easily controlled by spraying than by soil application, because of the high fixing capacity of some soils and other factors. In fact, it is difficult to correct soil deficiencies of the trace elements in mature fruit trees by additions to the soil. Iron and zinc are common examples.

As the application of large amounts of nutrients required in small quantities generally causes great damage to the crop, they must be used with caution. On calcareous soils, however, larger amounts can be applied with less chance of crop injury, with the exception of molybdenum. Indications are that high lime content and alkalinity of soils promote the availability of this element.

Deficiencies of calcium and magnesium are most common in acid, sandy soils. Yet magnesium deficiencies occur on many other soils, especially in warm or hot humid regions. The long-continued use of pure calcium limestone or of low-analysis superphosphate rich in calcium sulphate induces magnesium deficiency in many soils. Most legumes are quite sensitive to this deficiency. The use of dolomitic limestone, at rates up to 5 or 10 metric tons per hectare, is probably the most satisfactory treatment on acid soils. In some cases magnesium sulphate or dolomitic limestone is mixed with the fertilizer in small amounts to meet the immediate need. But on slightly acid, neutral, or alkaline soils, and especially on very sandy soils, dolomite acts too slowly to control magnesium deficiency, and more soluble compounds like magnesium sulphate have to be used. Some tomato growers in the United Kingdom have found that spraying the plants

with magnesium sulphate solution overcomes the acute magnesium deficiency induced by the increased use of chemical fertilizers and decreased use of farmyard manure. In the United States it has been shown that spraying apples with 1 kilogramme of magnesium sulphate in 40 litres of water can correct this deficiency. Work in that country has shown the difficulties involved in correcting severe magnesium deficiency in tung, apple, peach, and plum trees and in lucerne by soil applications of magnesium. Apparently the root system is affected by the deficiency to such an extent that it can scarcely absorb magnesium. Furthermore, magnesium deficiencies appear hard to correct if soil potassium is high. The potassium/magnesium ratio is very important in determining the uptake of magnesium; on low magnesium soils high potassium can induce severe magnesium deficiency. African oil palm, for example, is sensitive to the balance among potassium, magnesium, sodium, and phosphorus. Thus the addition of potassium alone may reduce magnesium intake and hence the phosphorus accumulation in the plant. For a more complete discussion of liming of acid soils, see the section on *Application of Liming Materials* at the end of this chapter.

Other things being equal, sulphur deficiency is more often found on acid than on alkaline soils because acid soils are more strongly leached. Near industrial and mining areas large amounts of sulphur are supplied in the rainfall or are absorbed by moist soil from the air. But in areas far from industry, where the winds originate over the ocean or other sulphur-free areas, soils may not receive these additions and may become very deficient in the element—even soils receiving only moderate rainfall. The sulphur contained in ordinary superphosphate or ammonium sulphate is sufficient to control the deficiency (see photo No. 25). Otherwise, 50 to 100 kilogrammes of flowers of sulphur or 100 to 400 kilogrammes of calcium sulphate (gypsum) per hectare are the usual applications. The flowers of sulphur should be broadcast and mixed with the soil, but the gypsum may either be broadcast or applied with other fertilizer.

Deficiencies of iron, manganese, and zinc occur most often in alkaline soils or in acid soils that have been overlimed. But this is not invariably the case; in South Australia, for instance, zinc deficiencies are common in acid and neutral as well as alkaline soils. The trouble is usually low availability rather than an absolute lack of the element; hence, alkalinity should be corrected as a primary measure to prevent the applied materials from rapidly reverting to unavailable forms. For this reason sprays are often used as a temporary corrective measure. For instance, to correct iron deficiency, a solution of 2 kilogrammes of ferrous (iron) sulphate and 1 kilogramme of lime per 200

litres of water can be used. Such a spray has been effective on pineapples in Hawaii. To correct zinc deficiency in some parts of South Australia, zinc is applied by swabbing pruned canes and vines or by spraying citrus and pine trees with a solution of 2 kilogrammes of zinc sulphate in 200 litres of water. In the United States, solutions of 1 to 2 kilogrammes of zinc sulphate with an equal amount of lime per 200 litres of water have proved satisfactory. Under suitable soil conditions, soil applications of 10 to 30 kilogrammes of zinc sulphate per hectare cover the needs of most crops on low zinc soils, though some large trees like pecans suffering from zinc deficiency may require several kilogrammes per tree. Manganese deficiency can be corrected by sprays using 1 to 2 kilogrammes of manganese sulphate with an equal amount of lime in 200 litres of water. Soil applications of 25 to 100 kilogrammes of manganese sulphate per hectare are often satisfactory for correcting manganese deficiency in slightly acid soils. High soil acidity increases the availability of soil manganese, and this may lead to manganese toxicity. Fruit trees are in general more strongly affected by these deficiencies than other crops.

Boron and copper deficiencies are often severe on organic soils, but may be found also on either acid or alkaline mineral soils. Boron deficiency is often induced by large applications of lime on acid soils, especially where little manure is used. Soil applications of 5 to 35 kilogrammes of borax and of copper sulphate per hectare, applied broadcast or mixed with fertilizer, are usually satisfactory treatments for boron and copper deficiencies. But borax should not be mixed with the fertilizer if it is placed in contact with the seed. Certain crops are particularly sensitive to boron toxicity, and on some soils even 25 kilogrammes of borax per hectare would be toxic. On soils high in organic matter, considerably higher applications of copper sulphate than those suggested can be used without toxic effects. For copper sprays, 1 to 2 kilogrammes of copper sulphate with an equal amount of lime in 200 litres of water has proved satisfactory. For boron, a solution of 1 to 2 kilogrammes of borax per 200 litres of water can be used. Root crops, certain vegetable crops, lucerne, and apples seem to be relatively sensitive to boron deficiency. In South Australia, lucerne and peas are especially sensitive to copper deficiency. When copper, zinc, and manganese are all needed, they can be used in one solution in about the following proportions. 1 kilogramme of copper sulphate, 1 kilogramme of manganese sulphate, 1 kilogramme of zinc sulphate, and about 2 kilogrammes of lime per 200 litres of water.

So far not many instances of molybdenum deficiency have been recorded. In South Australia, however, this deficiency is of sig-

nificance in agriculture, and in 1948 some 5,000 tons of superphosphate containing molybdenum were applied to pastures. Molybdenum deficiency seems to occur most often on leached acid soils derived from Cambrian and pre-Cambrian sedimentaries, especially on elevated slopes; on these, applications of molybdenum can be of much value. Herbage legumes appear to derive the greatest benefit from application of this element. Very small applications—about 50 to 100 grammes to the hectare—of compounds such as molybdenum trioxide and sodium and ammonium molybdates are needed to correct this kind of deficiency. Adding small quantities of molybdenum compounds to commonly used fertilizers has been effective, but very diluted sprays of molybdenum compounds (e.g., 70 grammes of sodium molybdate in 1,200 litres of water per hectare) can also be used.

APPLICATION OF ANIMAL MANURES

Three main problems must be dealt with in the use of manure: (1) Keeping losses at a minimum between the time the manure is produced and the time it is used in the fields; (2) applying the manure in such ways and at such times as to minimize losses; and (3) applying the manure to crops that will yield the largest return. The first of these is discussed in Chapter III.

Nitrogen may be lost from manure by volatilization and, along with other elements, by leaching. Losses up to one-half of the nutrient elements can occur through improper handling before and after application.

Liquid Manure. The nitrogen of liquid manure is highly perishable. Except for loss of ammonia nitrogen by volatilization, the principles governing its application are similar to those for nitrogen and potassium, since liquid manure is essentially a nitrogen-potassium mixture.

Danish experiments to determine yield increases from different methods of applying liquid manure show that ploughing the manure under immediately after application is most effective; harrowing immediately after application is 8 to 28 per cent less effective than ploughing; and harrowing delayed until the following day is 17 to 43 per cent less efficient than immediate harrowing. If liquid manure is spread on the surface of the soil for small grains and other non-cultivated crops, it should be mixed with the soil immediately by cultivation or ploughing. To minimize the loss of ammonia, fertilization and cultivation should be done on cool windless days. For cultivated crops the same method can be used, but it is better to apply the manure in a furrow alongside the row either at planting or as a

delayed side-dressing, immediately covering it with soil. The nitrogen in commercial fertilizers is preferable for top-dressing pastures or for delayed top-dressing of small grain crops because of the difficulty of controlling losses of ammonia from liquid manure. To minimize these losses, a simple machine, consisting of a tank and a pipe with several outlets protected by hollow teeth, has been used extensively in a number of European countries, and especially in Denmark, to inject liquid manure into the soil (see photo No. 26).

Solid Manure. The problem of nitrogen loss is somewhat less with solid manure because about half of the nitrogen is in organic forms not subject to loss by volatilization. Yet losses of ammonia nitrogen can be serious, because this kind of nitrogen is immediately available to crops.

Manure that is spread and allowed to lie on the surface loses much of its ammonia from drying in summer, from freezing in winter, and from surface wash in any season. In Denmark, manure incorporated into the soil a day after spreading has been found to be only 70 to 79 per cent as effective in increasing crop yields as manure that is turned under immediately after spreading. The depth of incorporation does not seem to be of great importance if the manure is covered enough for the soil to adsorb the ammonia.

Experiments show that applications made shortly before planting are more efficient than those made earlier. Losses in efficiency ranging from 8 to 61 per cent have been recorded in field experiments comparing autumn manuring with spring manuring for spring-planted crops. On the other hand, manure containing much relatively fresh straw or other plant residues should be worked into the soil well in advance, especially if moisture is low.

Spring top-dressing of manure has been found effective in getting good stands of legume and grass seedlings made in small grains. The value of manure for this purpose is probably due both to its nutrient content and to its effect as a mulch. For this purpose manure has some advantages over chemical fertilizers. On the other hand, the yield of the small-grain crop is likely to be increased more by manuring before ploughing than by top-dressing.

Most machinery for spreading manure is designed to distribute it fairly evenly. This method is probably the best for applying manure to non-cultivated crops. With widely spaced crops, like cucumbers and melons, manure is often worked into the soil in a limited area around the hill. It is often placed to good advantage in the row before planting potatoes and root crops. While such localized application may produce maximum increases in the yield of current crops, permitting a reduction in the rate of application so that more land can

be covered, uneven crop growth may result in subsequent years under certain climatic conditions.

APPLICATION OF SOIL AMENDMENTS

Soils vary widely in acidity and alkalinity, primarily according to the natural conditions under which they have developed and secondarily according to how they have been managed. Then, too, in many acid soils, there are great differences among the several layers or horizons; a soil may be acid on the surface layer and alkaline below the surface.

Liming Materials on Acid Soils. Soils vary in the *intensity* of their acidity and in the total *amount* of acidity in a unit of weight or volume. The intensity of the acidity is indicated by pH units. With this notation, pH 7 is neutral, lower values indicate acidity and higher values show alkalinity, about as follows:

	pH		pH
Extremely acid	below 4·5	Neutral[1]	6·6–7·3
Very strongly acid	4·5–5·0	Mildly alkaline	7·4–8·0
Strongly acid	5·1–5·5	Strongly alkaline	8·1–9·0
Medium acid	5·6–6·0	Very strongly alkaline	9·1 and higher
Slightly acid	6·1–6·5		

[1] Neutrality is pH 7·0, but for practical purposes soils between pH 6·6 and 7·3 are considered neutral.

Soils having the same pH—the same intensity of acidity—vary in the total amount of acidity and, hence, in the total amount of lime required to raise the pH a given amount. Other things being equal, acid soils rich in clay have higher reserves of acidity than sandy soils; those rich in organic matter have higher reserves than those low in organic matter; and acid soils developed in cool or temperate regions have higher reserves than those developed in warm-temperate or hot countries. Acid peats and mucks have very high reserves of acidity. The amount of lime necessary for an acid dark-coloured clay soil in western Europe would be far too high for a sandy soil near-by or for a clay soil in the tropics.

The lower need for lime on soils in the tropics, as compared to those of the temperate regions with comparable clay content, is extremely important. Many acid tropical soils are benefited by proper application of lime, especially when legumes are grown in pastures, with other crops in mixed cultures, or in rotations. But serious harm can be caused by using too much, thereby decreasing the availability of several mineral nutrients. Less lime can be used in the tropics than is recommended for western Europe. These differences are due mainly to unlike kinds of clay mineral produced under different soil-forming processes. In thinking about the soil as a medium for plant roots, we

are especially concerned with pH—the intensity of acidity. In thinking about changing the acidity of the soil, we are also concerned with the total amount of acid to be neutralized—the capacity factor.

Tests for Acidity. Most pH field tests are based on the use of "indicators," complex organic compounds in solution that change colour at specific pH values. Several kinds of reliable field kits can be purchased.

Despite the fact that pH measures only the intensity of the acidity —not the total reserve—nearly all reliable and convenient field tests for the lime requirement of soils use this measure. However, account is also taken of the factors influencing the total reserve acidity.

Effects of acidity and liming. Although acidity has some direct effect in retarding the growth of crop plants, many of the important effects are indirect.

The effect of soil reaction on the availability of plant nutrients to crops is discussed in Chapter II. Suffice it to mention here that nutrients generally are best conserved and kept available to plants around pH 6·5. The most favourable range for micro-organisms that fix atmospheric nitrogen and those that decompose organic matter lies between pH 6 and pH 8. Thus liming is frequently necessary on acid soils to obtain the beneficial effect of nitrogen fixation by bacteria on the roots of legumes.

Liming of acid clay soils improves their tilth through increased granulation. But the main good effects of liming on soil tilth are indirect—through widening the choice of crops to be grown, including the deeply rooted legumes. The common liming materials used to neutralize acid soils contain calcium or calcium and magnesium; part of the good effects of liming are due to increased supplies of these nutrients.

Plant Differences in pH Requirements. Soils vary in the intensity of their acidity from a little below pH 3·5 to a little above pH 9·5. Few if any plants grow over this entire range (see photo No. 27). Some grow over a large part of it; others do well only within narrow limits. A very high percentage of crop plants have pH 6·5 within their optimum range.

Table 7 lists the approximate optimum pH ranges of a few crop plants. Such guides are helpful in calculating the lime to apply and especially in selecting crops adapted to the soil in rotations and mixed cultures. But the figures are not precise. The optimum pH for plant growth varies with the type of soil. Also, climatically adapted crops grow better on soils of somewhat lower pH (more acid) in the sub-Arctic and cool-temperate regions than on soils of the temperate and warm-temperate regions.

Table 7. SOIL REACTION PREFERENCES OF CROP PLANTS

Common and botanical names	Optimum pH range	Common and botanical names	Optimum pH range
CEREALS		**HAY, FORAGE AND PASTURE GRASSES**	
Barley (Hordeum sativum)	*6·5–8·0	Bermuda grass (Cynodon dactylon)	6·0–7·0
Buckwheat (Fagopyrum esculentum)	*5·5–7·0*	Bluegrass, Canada (Poa compressa)	*6·0–7·5
Maize (Zea mays)	5·5–7·5	Bluegrass, Kentucky (P. pratensis)	5·5–7·5
Oats (Avena sativa)	5·0–7·5	Brome grass, awnless (Bromus inermis)	6·0–8·0
Rice (Oryza sativa)	5·0–6·5	Fescue, Chewing's (Festuca rubra var. fallax)	5·5–6·5
Rye (Secale cereale)	5·0–7·0*	Fescue, fine-leaved (F. capillata)	*6·5–7·5
Wheat (Triticum vulgare)	5·5–7·5	Fescue, meadow (F. pratensis)	4·5–7·0
		Fescue, sheep's (F. ovina)	4·5–6·0
LEGUMES, FIELD AND GARDEN		Italian rye grass (Lolium italicum)	*6·0–7·0*
Beans, field (Phaseolus vulgaris)	*6·0–7·5	Johnson grass (Sorghum halepense)	5·0–6·0
Beans, lima (P. limensis)	6·0–7·0	Meadow foxtail (Alopecurus pratensis)	*6·0–7·5
Beans, snap and wax (P. vulgaris)	6·0–7·5	Orchard grass (Dactylis glomerata)	6·0–7·0*
Beans, velvet (Stizolobium deeringianum)	5·5–7·0	Kafir corn (Sorghum vulgare var. caffrorum)	6·0–7·5
Clover, alsike (Trifolium hybridum)	5·5–7·5	Millet (Setaria italica)	5·0–6·5
Clover, berseem (T. alexandrinum)	6·0–7·5	Milo, dwarf yellow (Sorghum vulgare)	5·5–7·5
Clover, bur (Medicago denticulata)	5·0–6·5[1]	Redtop (Agrostis alba)	5·0–6·0
Clover, crimson (T. incarnatum)	5·5–7·0	Reed's canary gr. (Phalaris arundinacea)	6·0–7·0
Clover, Japan (Lespedeza striata)	5·5–6·5	Sudan grass (S. vulgare var. sudanense)	5·0–6·5
Clover, Ladino (T. repens)	5·6–7·0	Timothy (Phleum pratense)	5·5–8·0

Clover, mammoth, red (T. pratense, per.)	5·5–7·5
Clover, red (T. pratense)	6·0–7·5
Clover, sweet white (Melilotus alba)	*6·5–7·5
Clover, sweet yellow (M. officinalis)	*6·5–7·5
Clover, white (T. repens)	5·6–7·0
Cowpea (Vigna sinensis)	5·0–6·5[2]
Groundnuts (Arachis hypogaea)	5·3–6·6
Lespedeza, Jap. (Lespedeza japonica)	4·5–6·5
Lespedeza, Kor. (L. stipulacea)	4·5–6·5
Lucerne (Medicago sativa)	6·2–7·8
Lupine, blue (Lupinus hirsutus)	5·0–6·0
Lupine, white (L. albus)	5·5–7·0
Lupine, yellow (L. luteus)	5·0–6·0
Peas, canning and garden (Pisum sativum)	6·0–7·5
Serradella (Ornithopus sativus)	5·4–6·5*
Soybeans (Glycine max)	6·0–7·0
Vetch, hairy (Vicia villosa)	*5·2–7·0

MISCELLANEOUS FIELD CROPS

Beets, mangel-wurzel (Beta vulgaris var. cicla)	6·0–7·5
Beets, sugar (B. vulgaris)	*6·5–8·0
Broomcorn (Sorghum vulgare var. technicum)	5·0–6·5
Cotton, upland (Gossypium hirsutum)	5·0–6·0
Flax (Linum usitatissimum)	5·0–7·0
Hemp (Cannabis sativa)	6·0–7·0
Potatoes (Solanum tuberosum)	4·8–6·5[3]
Potatoes, sweet (Ipomaea batatas)	5·8–6·0*
Rape (Brassica napus)	6·0–7·5
Rutabaga (B. napobrassica)	5·5–7·0
Sugar cane (Saccharum officinarum)	*6·0–8·0
Sunflower (Helianthus annuus)	6·0–7·5
Tobacco (Nicotiana tabacum)	*5·5–7·5[4]
Turnips (Brassica rapa)	5·5–6·8

Plants listed may grow fairly well at least one-half pH unit below and above the optimum ranges given and some over an even wider range. If all other factors are favourable at high soil fertility levels, crops tolerate a greater degree of acidity than at low fertility levels. An asterisk (*) before a pH range signifies that fairly good growth occurs one full pH unit below the range thus marked. An asterisk after a pH range signifies occurrence of fairly good growth one full pH unit above the range marked.

[1] In South Australia, appears to grow most vigorously over the range of ph 6·5 to 8·0 and especially above pH 7·0.
[2] For disease control—mildew—pH 7·0.
[3] For scab control—pH 5·6.
[4] For disease control—pH 6·0.

Then, too, a soil may be acid throughout the root zone or only at the surface. If only the surface is acid, a little lime may promote early growth and, once established, the plant roots can feed on the layers of soil beneath.

With a few crops, disease organisms tolerate less acidity than the plant. For instance, to control potato scab, the soil should be kept at pH 5·6. For similar reasons the pH of soils used for tobacco or egg-plant should be below 6·0.

Amount of lime to apply. Rates of liming depend upon several factors:

(1) The pH or intensity of the soil acidity;
(2) The total acidity, influenced by the amount and kind of clay and the amount of organic matter;
(3) The pH of layers beneath the surface soil;
(4) The crop requirement, considering all the crops in the culture or rotation;
(5) The kind and purity of material used, including fineness or particle size.

Table 8 may serve as a very general guide to liming, but field trials on local soil types are needed to give more precise predictions.

Lime may be applied before ploughing or applied on ploughed land and worked into the soil with a harrow. Especially with heavy applications, a part may be ploughed under and a part harrowed in after ploughing to hasten favourable results. When large applications of lime are needed, it is wise to make two or more light applications rather than one heavy application; this practice prevents local over-liming. Ordinarily a change of more than one pH unit by one application of lime should not be attempted. For example, if the field soil has a pH of 4·5, it is better to change it to pH 5·5 one year and to pH 6·5 the following year or even two years later. Between these applications, checks can be made to determine the rates more precisely. The danger of over-liming is greatest with burned or hydrated lime and least with dolomitic limestone. Pastures and long leys may be treated with broadcast applications on the surface. Lime leaches down into the soil more slowly than nitrogen, but more rapidly than phosphate fertilizers.

There is a growing need to emphasize the use of dolomitic limestone containing both calcium and magnesium in preference to limestone made up wholly of calcium compounds.

Table 8. APPROXIMATE AMOUNTS OF FINELY GROUND LIMESTONE[1] NEEDED TO RAISE THE pH OF AN 18-CENTIMETRE LAYER OF SOIL

Soil regions and textural types	Limestone requirements		
	From pH 3·5 to pH 4·5	From pH 4·5 to pH 5·5	From pH 5·5 to pH 6·5
	(Metric tons per hectare[2])		
Soils of warm-temperate and tropical regions:[3]			
Sand and loamy sand	0·6	0·6	0·9
Sandy loam	([4])	1·1	1·5
Loam	([4])	1·7	2·2
Silt Loam	([4])	2·6	3·2
Clay loam	([4])	3·4	4·3
Muck	5·6	7·5	8·6
Soils of cool-temperate and temperate regions:[5]			
Sand and loamy sand	0·9	1·1	1·3
Sandy loam	([4])	1·9	2·8
Loam	([4])	2·6	3·7
Silt loam	([4])	3·4	4·5
Clay loam	([4])	4·3	5·2
Muck	6·5	8·6	9·7

[1] All through a 2-mm. mesh screen and at least one-half through a 0·15-mm. mesh screen. With coarser materials, applications need to be greater. For burned lime about one-half the amounts given are used; for hydrated lime about three-quarters.

[2] The suggestions for muck soils are for those essentially free of sand and clay. For those containing much sand or clay the amounts should be reduced to values midway between those given for muck and the corresponding class of mineral soil. If the mineral soils are unusually low in organic matter, the recommendations should be reduced about 25 per cent; if unusually high, increased by about 25 per cent.

[3] Red-Yellow Podzolic, Red Latosol, etc.

[4] No recommendation given.

[5] Podzol, Grey-Brown Podzolic, Brown Forest, Brown Podzolic, etc.

Soil Amendments on Alkali Soils. Generally, alkali soils are too rich in sodium clay or sodium clay and sodium carbonate. The extreme alkalinity may be reduced by substituting calcium for the sodium. Where drainage is good, or is made good, additions of calcium sulphate will accomplish this purpose. The sodium carbonate is changed to calcium carbonate; the sodium clay is changed to calcium clay, and the sodium sulphate leaves the soil in the drainage water. If a soil contains calcium carbonate, the same effect may be produced by adding sulphur. This is changed by soil micro-organisms to sulphuric acid, which reacts with the calcium carbonate to form calcium sulphate.[1]

The amendment of alkali soils by the addition of sulphur and/or gypsum is usually accompanied by irrigation to get water into the soil and, with good drainage, to carry off the excess. The water is needed to permit oxidation of sulphur, eventually to sulphuric acid; to permit chemical reaction between the soil improver and the soil; and to remove unwanted products of the reaction, mainly sodium sulphate.

[1] See Greene, H., *Using Salty Land.* Washington, D.C.: FAO Agricultural Studies No. 3. Pp. 49. (English edition out of print. French edition available.)

Gypsum can be broadcast or incorporated with the surface soil in amounts running up to 50 metric tons per hectare, though 5 to 10 tons per hectare is a more usual dressing. The amount needed can be determined accurately only by chemical examination. If only a shallow layer of surface soil needs treatment and gypsum is present in the immediate subsoil, deep ploughing accompanied by a light addition of gypsum makes the required improvement. Sulphur should usually be applied in small amounts, not exceeding 1 ton per hectare. The dose can be repeated if necessary. Too heavy an application produces a high acidity. Sulphur should be used only on soils containing substantial amounts of calcium carbonate.

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Photo No. 26. A liquid manure drill, Denmark. The liquid manure is led directly down into the soil from the barrel through a rubber tube, pipes, and hollow harrow teeth. (The small wheels on the drill are used to transport the drill on the road.)

Photo by Karsten Iversen.

Photo No. 27. Here, in an experimental forest nursery near Oxford, England, is a series of small plots made acid with aluminium sulphate and alkaline with lime in order to test the growth of green manures. In the foreground, at the highly acid end on the right, buckwheat is doing very poorly.

Photo by Charles E. Kellogg.

Photo No. 28. The good effect of an herbage-legume rotation on the yield of maize (corn) grown on Marshall silt-loam, a Prairie soil in south-western Iowa, U.S.A. This is a deep, naturally fertile soil, slightly acid to neutral, developed from loess. The maize on the left was grown in a two-year rotation of maize and oats with a sweet clover (Melilotus alba) *catch crop. It yielded 3·4 metric tons of grain per hectare. The maize on the right is the second-year crop in a 3-year rotation of maize, maize, oats with a sweet clover catch crop. It yielded 1·6 metric tons of grain per hectare. The maize on the right is quite deficient in nitrogen. On this soil maize cannot have enough nitrogen for two crops in a 3-year rotation.*

Photo by W. H. Pierre and C. A. Black.

Photo No. 29. Rolling (Waikare) clay soil—an irregularly podzolized Brown Forest soil with high phosphate fixation—north of Auckland, New Zealand. Essentially worthless scrub on the left. Good permanent dairy pasture on the right, yielding about 110 to 135 kilogrammes of butterfat per hectare annually. Mainly Italian rye grass, paspalum, and white clover seeded after treatment with phosphate fertilizer and some lime.

Photo by Charles E. Kellogg.

VI

CROP SEQUENCES AND FERTILIZERS

WORLD experience has shown that greater production can usually be achieved when crops are grown in sequence than when the same crops are grown on the same soil year after year. Such sequences are usually referred to as rotations. In this chapter we are concerned with rotations in relation to fertilizers and animal manures.

EFFICIENT USE OF FERTILIZERS IN ROTATIONS

Many rotations have become well established as important elements in good farming, and their benefits have been demonstrated innumerable times (see photo No. 28). Some of the more important benefits of a good rotation are:

(1) Increased organic matter, nitrogen supply, and water-holding capacity of the soil, especially with deeply rooted legumes or legume-grass mixtures in the rotation.
(2) Growth of crops capable of feeding at various soil depths, with more efficient use of plant nutrients and soil moisture. Deep-rooted crops bring plant nutrients from the lower layers of the soil and leave them as crop residues in the upper levels, where they can be used by shallow-rooted crops. Increased permeability of the lower soil to air and water, by which all other crops benefit in the rotation, results from growing deep-rooted crops.
(3) Growth of crops that differ in the quantitative requirements for different plant nutrients.
(4) Greater possibility of keeping land under suitable crops most of the year.
(5) Control of run-off, erosion, and leaching, and improvement of soil structure and tilth.
(6) Control of weeds, diseases, and pests.
(7) Better use of labour and farm machinery and more secure financial returns from the farm.
(8) Most efficient use of fertilizers.

Rotations are most thoroughly established in the temperate zones where the precipitation is sufficient to grow a variety of crops,

including cereals, grasses, legumes, and roots, and in areas where irrigation water is available. Fertilizers and manures can be used most effectively with the rotation best adapted to the local climate and soil type. Where poor rotations are used, or no rotation at all is followed, much of the benefit that can be obtained by using fertilizer materials in a sound rotation programme is lost.

Fertilizers improve yields of crops grown in rotation (see photo No. 30) and permit the raising in rotation of more valuable crops which would otherwise give poor yields or could not be grown at all. Clover can be grown successfully by liming acid soils. Lucerne is particularly sensitive to soil acidity and requires a great deal of phosphorus and potash; potassium and phosphate fertilizers and lime have done much to spread this crop. Some soils are too acid for wheat or barley, and only fit for oats and rye. Lime can make these soils suitable for wheat and barley. One of the chief purposes of fertilizers is to expand the range of crops that can be grown (see photo No. 29).

To illustrate how the use of manures and fertilizers can be correlated with the cultivation of various crops in a rotation, a few rotations in various countries are given as examples.

(1) *China.* Two of many rotations of the central rice region.

One-year rotation:	*Astragalus sinensis*	—	Winter
	Rice	—	Summer
Two-year rotation:			
First year:	*Astragalus sinensis*	—	Winter
	Rice	—	Summer
Second year:	Wheat, barley, or rapeseed	—	Winter
	Rice	—	Summer

This two-year rotation can be expanded into a longer rotation by growing different crops in winter.

In the rotations used in the rice-growing region of central China, *Astragalus* is grown as a soil improver. The vegetative portion of the crop may be cut and carried to other fields to be ploughed under, it may be fed to hogs, or it may be used for composting.

Astragalus roots and residues are ploughed under in preparation of land for rice. Barnyard manure, night soil, and, in limited areas, ammonium sulphate are used for fertilizing rice. Larger quantities are applied on rice land not growing a previous legume crop. Good yields of rice depend to a great extent on adequate manuring and, since this is their most important food crop. Chinese farmers spare no effort in manuring and fertilizing it.

When winter wheat follows rice it may receive an application of night soil in the early spring or of ammonium sulphate, if available. Phosphate and potash chemical fertilizers have been used only to a

Photo No. 30. Fertilizer and lime increase yields in a rotation. Experiment conducted by the Ontario Agricultural College, Guelph, Ontario, Canada, on wheat and clover grown near Welland, in a rotation from 1922 to 1942 as follows:

Wheat, seeded to red clover, alsike clover, and timothy hay mixture; hay; maize; oats, seeded to sweet clover (Melilotus alba); *hay.*

The soil is Welland clay loam, a medium acid (pH 5·8) Grey-Brown Podzolic soil, extremely low in available phosphorus and nitrogen and with an impervious subsoil. The pictures show the wheat crop (above) in 1938 and the clover crop (below) on the same plots in 1939. No fertilizer or lime was applied to the plot on the right, whereas on that to the left fertilizers have been applied for wheat and maize in the rotation since 1934. For wheat a mixture of fertilizers was drilled with a combination grain drill: Nitrogen as ammonium sulphate was applied at 22 kilogrammes per hectare, phosphorus as superphosphate at 72 kilogrammes (P_2O_5) per hectare, and potassium as potassium chloride at 56 kilogrammes (K_2O) per hectare. Similar dressings were used for maize, but the fertilizer was broadcast and disked in.

In preparation for maize, both plots received manure applied at a rate proportional to the yields of crops on each plot. In addition to the fertilizer treatment, the plot on the left received a dressing of 4·5 metric tons per hectare of crushed dolomitic limestone in 1934, which left the soil only slightly acid (pH 6·3). In 1938 the yield on the fertilized plot on the left was 2·4 metric tons of threshed wheat per hectare as against 0·6 metric tons on the unfertilized plot on the right. Similarly in 1939 the fertilized plot gave 2·6 metric tons of hay per hectare as compared to 1·6 metric tons on the unfertilized plot. The comparatively low yield of hay was due to extremely dry weather during the early summer of 1938.

Photos by courtesy of F. Morwick and N. J. Thomas.

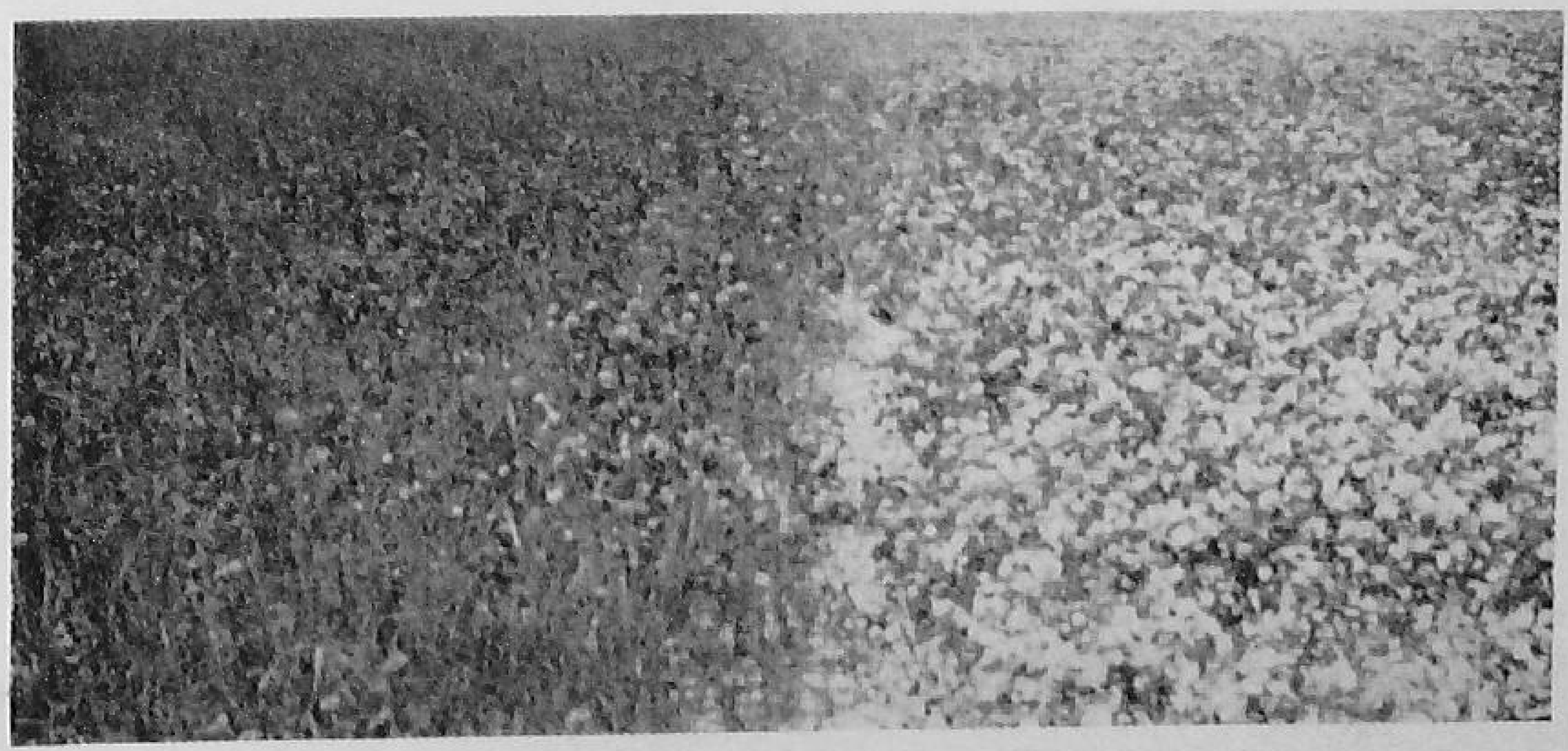


Photo No. 31. First stage in the rotation of food crops near Yangambi, Belgian Congo, under the corridor system. The trees have been cut, but the land has not been burned.

Photos by Charles E. Kellogg.

Photo No. 32. Rotation of food crops near Yangambi, Belgian Congo, under the corridor system, about 2 years after the start. The maize and rice have long been harvested, and the cassava is being dug. Soon the bananas will be cut, while the second-growth cassava makes a ground cover.

limited extent in China, although experimental results have shown that crops on many soils would benefit from applications of fertilizers containing these plant nutrients. That Chinese farmers fully realize the importance of rotation and manuring is indicated by many of their adages, two of which are:

> Millet sown in a millet field
> More tears than ears will yield.
>
> Dungless paddies, say the scholars,
> Are like traders without dollars.

(2) *Egypt*. Three-year rotation, one of the most commonly used.

First year:	Berseem (*Trifolium alexandrinum*) Maize	— —	Winter Summer
Second year:	Fallow until February Cotton planted in the early spring		
Third year:	Wheat, barley, or broad beans (*Vicia*) Fallow or maize	— —	Winter Summer

In this rotation, berseem, the winter legume, receives a dressing of superphosphate. In Egypt phosphates increase the yield of winter legumes, but not of summer legumes such as groundnuts. Four to six cuttings of berseem are taken for hay and then the soil receives a dressing of manure and is prepared for the maize crop. The application of manure is not so heavy for maize when it follows berseem as when it succeeds winter wheat, because berseem ploughed under provides considerable nitrogen and organic matter. In addition to manure, the maize crop receives a top-dressing of sodium nitrate. Although this is the type of nitrogen fertilizer most commonly used in Egypt, there is a growing realization that ammonium sulphate and ammonium nitrate are better, at least for alkaline soils, which are common in the northern part of the country. After maize, the land is left fallow and is planted to cotton in the spring. Cotton following bare fallow does not as a rule receive any fertilizer; however, a dressing of nitrate is sometimes given to rich deep soils, but not to shallow waterlogged soils.

After cotton, the land may be planted to winter wheat, barley, or broad beans. Wheat and barley receive a top-dressing of nitrate about a month after sowing. When broad beans are the winter crop, the soil often receives an application of superphosphate before seeding.

After winter wheat, the land is left fallow or, on less prosperous farms where there is an immediate necessity to raise as many crops as

possible, planted with maize. The maize gets a heavy dressing of farmyard manure and an application of nitrate.

(3) *England.* Norfolk four-course rotation.

First year: Roots (potatoes, sugar beets, mangolds, swedes)
Second year: Spring-sown cereal (barley or oats) and "seeds" (grasses and clover)
Third year: "Seeds" (grasses and clover)
Fourth year: Winter cereal (wheat or oats)

In the Norfolk four-course rotation, which is one of the oldest rotations used in England, roots receive manure if it is available, potatoes being given preference if the manure supply is limited. Since the fertilizer requirements of the root crops—sugar beets, mangolds, potatoes, and swede turnips—differ, their fertilizer treatments also differ, depending on whether they are grown with manure. Without manure, sugar beets and mangolds are given common salt and chemical fertilizers containing roughly equal amounts of nitrogen, phosphate, and potash. Potatoes are given a little more potash than phosphate or nitrogen, whereas swedes receive a little more phosphate than nitrogen and potash, especially in wet areas, to start the crop off well. With manure, sugar beets and mangolds should still receive common salt, but probably need only nitrogen and possibly a little phosphate fertilizer. Potatoes should have a fertilizer dressing containing nitrogen, phosphate, and potash in roughly equal proportions. Swedes probably need nitrogen and phosphate fertilizer.

Barley, following roots, probably receives a light application of nitrogen; after dressings of manure and fertilizer for the root crops, the soil is in good condition. Furthermore, it is best not to stimulate too heavy a growth of barley, to the detriment of undersown "seeds." On sandy soils especially, a dressing of phosphate and potash may be found advantageous to assure a good catch of clover in the hay mixture. If there is a good proportion of clover, the mixture is probably not fertilized in the year it is cut. On the other hand, when grasses predominate, nitrogenous dressings give good results.

Winter wheat following the hay crop benefits from ploughing the sod under, but some phosphate fertilizer may be used at seeding time to give the crop a good start. It should also receive a dressing of nitrogen fertilizer in the spring, preferably in two applications. All cereals in the United Kingdom respond well to nitrogenous fertilizers. Since wheat is one of the major cash crops, fertilizing usually pays.

(4) *France.* One of the more interesting rotations of northern France and the Paris area is one that lasts eight or nine years.

First year:	Sugar beets or potatoes
Second year:	Winter wheat
Third year:	Oats or barley
Fourth year:	Sugar beets or potatoes
Fifth year:	Winter wheat
Sixth year:	Oats or barley
Seventh, eighth, and possibly ninth years:	Lucerne

In this rotation, the sugar-beet and potato land receives a dressing of farmyard manure, compost, or sewage sludge before ploughing if any of these are available. At seeding time these crops receive a heavy application of chemical fertilizers containing more potash than nitrogen or phosphate. Soils of these areas are somewhat deficient in potash and these crops respond well to it. Potatoes especially are heavily fertilized with potash. Beet tops are ploughed under or fed to sheep on the land.

Winter wheat following the root crop receives at seeding time an application of chemical fertilizers containing only nitrogen, or at least more nitrogen than phosphate and potash. In the spring it is given a nitrogen dressing. The oats or barley after wheat is given the same type of fertilization as the wheat.

Lucerne is grown to supply livestock feed and to add organic matter and nitrogen to the soil. Even if no stock is kept, lucerne is still included in the rotation as a soil improver, and the hay is sold. In the last year only two cuttings are made; the third growth is ploughed under.

(5) *Union of South Africa.* In the maize belt, monoculture is still largely practised in spite of advice to the contrary. Rotations are, however, gradually replacing monoculture, and wheat and oats are now more commonly grown in certain districts. The following example shows a four-year rotation.

First year:	Maize
Second year:	Legumes (groundnuts, cowpeas, etc.)
Third year:	Wheat
Fourth year:	Teff (Eragrostis tef) or other hay crop

The maize belt is in the summer rainfall region and, except in the Southern Free State, usually no crops are grown during the winter unless irrigation water is available. Maize receives a dressing of 100 kilogrammes of superphosphate per hectare. Soils in the Union of South Africa are deficient in phosphorus. Fertilizer is not usually applied to the legumes in the second year of the rotation. The wheat crop is given a dressing of a fertilizer containing both nitrogen and phosphate (4:14:0) at the rate of 150 kilogrammes per hectare, and the

teff or other hay crop following wheat benefits from the residual effect of this fertilizer treatment. For some years now experimental work has shown that a system of rotation containing a 2-to-3-year grass ley gives good results, and efforts are being made to introduce this type of rotation.

(6) *United States.* One of the better rotations of the Corn Belt.

First year:	Maize
Second year:	Oats
Third year:	Wheat (mixed hay seeded with the wheat)
Fourth and fifth years:	Mixed hay for two years (clover and timothy)

In this rotation, manure is used on the maize. Fertilizers are applied on maize and wheat, but oats and hay usually depend on the residual effect of the fertilizers and manure.

The fertilizer for a rotation needs to be carefully planned. Consideration must be given to the type of soil, the requirements of crops, the response of individual crops, the availability of manure and fertilizer, and the residual effects each crop has on the soil.

To maintain their productivity, most soils must be periodically devoted to legumes or legume-grass mixtures, but there are exceptions. Some soil types, including many Alluvial soils, do not lose their structure with tillage. They can be supplied with nutrients and organic matter by fertilizers and manure or composts.

On some soils in the tropics mixed cultures of such crops as maize, rice, cassava, and bananas grown together are superior to separate rotation of these crops. Usually rubber, cacao, oil palm, citrus, and similar crops do better if other plants are grown with them as cover or green-manure crops. All the reasons are not yet clear.

Various crop rotations are being experimentally investigated by agricultural departments of the various territories of British West Africa and British East Africa with a view to increasing food production and at the same time conserving the soil. For these experiments the effects of animal manure and of mineral fertilizers are being specifically studied.

Monocultures and Fertilizers

The general experience is against monoculture, yet on many soils in the tropics, especially young soils from alluvium, volcanic rock, and basalt, sugar cane has been grown continuously for many successive years with good results. A few monocultures have been successful in the temperate regions also. In the state of Maine (U.S.A.), where potatoes are grown on a large scale, there are fields which are planted to this crop year after year. There are others on which

potatoes are raised four years out of five, three years out of four, or two years out of three. The yield is maintained by using as much as two tons per hectare of chemical fertilizers, containing nitrogen, phosphorus, potash, and magnesium. Recent experiments indicate that smaller applications of phosphate and potash would suffice on soils that have been fertilized a great many times. If manure is used, or if potatoes follow a good growth of clover which has been ploughed under, the amount of chemical fertilizer can be reduced by about 20 per cent. On most farms, land is economically seeded down for a year to clovers that are then ploughed under.

In Natal, South Africa, the chief fertilizer used on sugar cane grown successfully in monoculture is superphosphate, and the best results are obtained from applications of 600 kilogrammes per hectare at first planting and 300 kilogrammes on subsequent ratoons. Phosphate fertilizer is needed because nearly all South African soils are deficient in phosphorus. Clarification residues from the sugar factories, containing lime, are also commonly used. Before World War II it was a fairly general practice to apply nitrogen fertilizers, mainly ammonium sulphate, to this crop (500-1000 kg. per hectare), with consequent increases in sugar yields. Unfortunately, because of the shortage of nitrogen fertilizers during the war and since, this practice has not been fully maintained, with depressing effects on yields of sugar cane. Some potassium fertilizers are also used. A further practice, strongly advocated but not always followed, is to leave the trimmings on the ground at the time of cutting. The good effect of the trash or trimmings is to maintain the humus content of the soil, hence increasing its water absorption and retention and assisting in the maintenance of granulation. The number of ratoon crops taken varies from three to four. If soil humus has been maintained by good management, replanting can take place immediately. Green-manure crops such as sunn hemp (*Crotalaria juncea*) are now quite frequently grown before the cane is replanted. In the Punjab it is the nitrogen fertilizers that are chiefly needed for sugar cane.

In Louisiana, U.S.A., on the alluvial land of the lower Mississippi Delta, yields of sugar cane are maintained by ploughing the land after the second ratoon crop has been cut and seeding it for the winter to such crops as cowpeas or soybeans. These leguminous crops are ploughed under in the spring, before the sugar cane is planted again. The legumes supply organic matter and much-needed nitrogen. After the sugar cane is planted, it is side-dressed yearly with 560 to 1,680 kilogrammes of chemical fertilizer per hectare, containing chiefly nitrogen and phosphorus, since the soils contain abundant potash. In Florida, U.S.A., on the other hand, where sugar cane is grown

on muck soils rich in nitrogen, there is a need for phosphorus and potash and for such nutrients as manganese, copper, and zinc. Chemical fertilizers containing these nutrients are supplied at planting, and potash side-dressings are repeated yearly.

In Hawaii, on Reddish-Brown Latosols (Reddish-Brown Lateritic) from basalt, many plantation managers have not found it necessary to save crop residues or add organics to maintain the structure of their soils. But large amounts of nitrogen, phosphorus, and potassium are used. Yet in the more humid parts of Hawaii the productivity of some of these soils is declining, and it is apparently restored by a period in grass.

Many soils in the tropics, however, will not endure continuous cultivation and exposure to the sun. Some become over-granulated, and so loose that there is not enough contact between soil and roots for the plants to take up sufficient water and nutrients. Others bake into hard masses. In either case they can be restored only by a long period of fallow under grass, shrubs, or trees, depending upon the climate and local soil.

Shifting Cultivation

In tropical and subtropical Asia, Africa, and America, "shifting cultivation" has been practised for centuries as a means of obtaining better crop yields. It has assumed various forms in different regions, chiefly in response to varying physical factors, particularly rainfall.

Tropical areas with a rainy season of two to four months are mostly under grass and support nomadic cattle-owning tribes. Land receiving four to six months of rain usually has open woodland in which primitive tribes practise shifting cultivation. If the rainy season exceeds six months, the land is mostly under forest. Here, also, clearings made for cultivation are abandoned after a few years. With shifting cultivation in its crudest form, tracts of land are used for agriculture or grazing until yields decline, and then they are abandoned for new areas. Changes in the pattern of life, the demand for new types of crops and for increased agricultural production, and the realization that even under a system of shifting cultivation better use of land can be made has led to improvements in this system of cultivation in some parts of the world.

For instance, in certain areas of the Belgian Congo a system of cropping is used which in reality is a long-term rotation of forest and field crops, the forest occupying the land as a cover or green-manure crop. Under this system the forest land is divided into long strips or corridors about 100 metres wide, the strips running east and west to let in the light. One corridor is needed for each year of cropping and

Photo No. 33. Elephant grass (Pennisetum purpureum) *growing on an Alluvial glei soil associated with Red Latosols under forest, Low Congo near Luki, Belgian Congo.*

Photo by courtesy of Charles E. Kellogg.

Photo No. 34. *Regeneration in the corridor system near Yangambi, Belgian Congo, a year and a half after a crop of groundnuts* (Arachis hypogaea) *and seven and a half years after the original clearing of the corridor. Regeneration is much slower after groundnuts than after cassava. In twelve more years, this corridor will again be ready for a rotation of food crops.*

Photos by Charles E. Kellogg.

Photo No. 35. *Elephant grass* (Pennisetum purpureum) *is cut and chopped fine in the field and fed to dairy cows. Near Honolulu, Territory of Hawaii.*

one for each year under forest fallow. These can be arranged so that forest in some stage borders each cultivated corridor. The comparatively narrow corridor makes for quick regeneration of forest when the corridor is abandoned to fallow. After the land in the corridor is cleared, with the brush burned and the logs left to rot, it is put under field crops for some four years (see photo No. 31). Many combinations of crops and rotations are possible. For instance, in the first two years a mixed culture of maize, cassava, rice, and bananas may be grown (see photo No. 32). In the third year the land may be planted to a single leguminous food crop, and in the fourth to a fibre crop that favours the spread of trees from the forest corridors (photo No. 34). The mixed culture of crops with differing vegetative cycles assures continuous cover for the land, with protection against the sun and beating rain, and more effective utilization of the large quantities of plant nutrients rapidly released by the destruction of forest cover. Moreover, crops with different root systems feed at different soil levels, and this also contributes to a more efficient use of plant nutrients.

Forest fallow lasting some twelve years has been adopted, chiefly because this has been found the best method of regenerating soil fertility in the tropical climate of the region under existing economic and social conditions. The forest vegetation of different levels provides a good cover for the soil. The deep roots of trees tap new reserves of plant nutrients in the lower soil layers and absorb nutrients leached down during the years that the land was in field crops. Large quantities of these nutrients become part of the living organic matter of trunks, branches, and leaves of forest vegetation, which are released for the use of crop plants when the forest is again cut down. Under forest vegetation the soil structure is also greatly improved.

This forest fallow system is an example of success achieved by the use of improved native practices adopted in preference to recognized practices of temperate and other regions, which would have been entirely unsuited to the Belgian Congo. Research is now in progress to find crop plants of economic value that can be used to shorten or replace the forest fallow. None of the legumes so far tried has proved suitable, but a number of fodder grasses, such as *Panicum maximum*, *Cynodon plectostachyon*, and *Brachyaria bryzanta*, are showing promise. Should these plants prove satisfactory, their use in rotations would facilitate the production of improved breeds of cattle in the region.

Vast possibilities exist in the cultivation of the Alluvial soils and islands recently formed by the rivers of the central Congo Basin. Trials have indicated the great possibilities of production on these

soils and the necessity for adopting the appropriate methods of cultivation.

In Burma, India, Malaya, and the Philippines, when valueless wild forests are cut for a short period of field-crop production, these areas are then replanted to desired sorts of trees. In some parts of China, also, rotation of forest and field crops is practised. These are but a few examples of how the ancient practice of shifting cultivation is being gradually systematized. Under this method of cropping, as with more usual field-crop rotations, manures, composts, soil amendments, and probably chemical fertilizers could play a useful role, but a great deal of research and experimental work is required before informed recommendations can be made. Even should fertilizers be recommended, there would always remain the question of transportation to areas far removed from industrial centres.

An enormous need exists for thus improving the older systems of shifting cultivation on tropical soils. With more fertilizers available in the tropics, the system may be further improved. It is along those lines that improvement lies, not in attempts simply to eliminate the practice.

Green Manuring and Cover Crops

Green manuring is the practice of growing crops for the specific purpose of incorporating them into the soil. Turned under, they add organic matter, return to the upper soil plant nutrients taken up by the crop from deeper layers, improve the structure of the soil, hold nutrients that would have been lost by leaching, and, when legumes are used, provide additional nitrogen for succeeding crops. Legumes, non-legumes, or mixtures may be used for this purpose. Quick-growing crops are preferred for green manuring. Where bulk is of first importance, such crops as rye, sorghum, or mustard may be better than legumes. Often, however, non-leguminous crops do not contain sufficient nitrogen to provide for their decomposition by soil micro-organisms, which consequently draw on soil nitrogen to the detriment of the following crop. A legume crop, on the other hand, carries with it more than enough nitrogen for its decay, and the excess becomes available to the following crop. Green-manure crops frequently benefit from fertilizers to get them established and to promote good growth and decomposition.

Green-manure crops are often used as cover crops to prevent soil erosion. The growing crop protects the soil from the impact of rain and retards run-off. Turning under the cover crop adds to the organic matter of the soil and increases its permeability, enabling the water to soak in more rapidly and decreasing run-off and erosion. In

sub-Arctic and cool-temperate regions, cover crops are generally unnecessary because these soils are deeply frozen in winter and do not leach. Moreover, as it is important to prepare the soil and plant the crops as early as possible in the spring, mulches and cover crops must be avoided because they delay the warming of the soil.

Giving over the entire crop season to a green-manure crop is not generally considered economic, but is sometimes necessary. For instance, lupines have been grown quite extensively in Germany as green-manure crops to build up the fertility of poor sandy soils. The practice may be justified sometimes, also, if the green-manure crop is followed by an expecially valuable crop.

Green manuring is most common in regions of abundant moisture. In warm-temperate regions, winters are too cool for crops such as maize or cotton, but warm enough for grasses and vegetative legumes. In these regions green-manure crops may be grown to advantage in this season, absorbing nutrients and conserving them for the next crop.

The use of green-manure or cover crops is quite common also in the orchards of the temperate regions. In the United States, for example, the standard procedure for peaches, citrus, and pecans is to grow annual crops like rye, or rye and vetch, in the more central areas and crimson clover, cowpeas, or crotalaria in the southern areas. A large part of the fertilizer used in growing these crops is returned to the soil when they are turned under. In the warm-temperate or the winter-rainfall area of the Union of South Africa, the standard practice for deciduous fruit trees is to grow a cover crop, preferably a legume (usually lupine), which is ploughed under in the spring. The cover crop receives a dressing of phosphate, but nitrogen is also applied in the spring.

Various opinions are held on the value and methods of green manuring in tropical regions. Although some valuable experimental work has been done on this problem, much remains to be done to obtain a clearer understanding of the tropical conditions under which green manuring can be used to good advantage. High average temperature and seasonal high moisture content of the soil in much of the tropics make for rapid decomposition of organic matter. Stirring the soil further accelerates this process. Some experiments in Nigeria, Trinidad, and elsewhere seem to show that in some hot countries the chief benefit from green-manure crops is derived from their mineral rather than their organic content. The good effects of such crops are not long-lasting, probably because of the excessively rapid decomposition of plant material incorporated into the soil.

It has been found in certain regions, such as Uganda, that green-

manure crops do not greatly improve soil structure, though they may conserve plant nutrients. Evidence is accumulating, however, that soil structure can be improved in these regions by growing a perennial grass for a number of years. Not only does the grass provide organic matter, but the roots have a direct mechanical effect. In Uganda, for instance, a resting period of two or three years under elephant grass (*Pennisetum purpureum*) is becoming a recognized feature of a soil-fertility conserving rotation (see photos Nos. 33 and 35). There is also evidence that grasses differ widely in their effect on soil structure.

At the Imperial College of Agriculture, Trinidad, British West Indies, considerable success is being achieved by growing certain leguminous climbing or twining plants with tall bunch-grasses, such as elephant grass (*Pennisetum purpureum*), to enrich the soil and improve its structure while at the same time yielding a steady supply of fodder for stock. The climbers that serve best do not interfere with the growth of the grass, but simply use its stems as supports.

In evaluating water supply for green-manure crops, three requirements have to be considered: There should be enough moisture, from rain or irrigation, to grow a satisfactory green-manure crop; enough moisture for its decomposition when it is dug in; and an ample water supply for the succeeding crop. In certain parts of the tropics it is hard to meet all these requirements because of the seasonal distribution of rain. Under these circumstances water becomes the determining factor as to where and when green-manure crops should be grown.

The economics of green manuring must always be considered. Loss of the land for economic use during part of the year is a serious difficulty in many circumstances. This problem can be met in part by intersowing a green-manure crop with the main crop, by growing a green-manure crop on a small area and using some of the top growth on other fields, or by making use of the leaves, tender twigs, and stems of trees and wild plants.

In the tropics, green-manuring or cover crops, trees, bushes, or annual plants may be grown to shade the soil from the intense heat of the sun and to keep the reflected heat from injuring commercial trees. When grown for these additional purposes, they are sometimes known as shade crops.

The use of green-manuring crops such as sunn hemp (*Crotalaria juncea*) and *Dhaincha* (*Sesbania aculeata*) for rice, sugar cane, cotton, and other crops has proved successful in many parts of India when adequate water is available. Leguminous trees such as the *Sau* tree (*Albizzia stipulata*), *Dadap* (*Erythrina lithosperma*), and the shrub *Boga medeloa* (*Tephrosia candida*) have also been used to advantage in tea plantations of India. These trees and shrubs provide some

Photo No. 36. These oranges in the Low Congo had been planted about 2 years and were irrigated for the first 20 months or so. Since they are not irrigated any more, it is important that they have a proper ground cover. On this heavy Alluvial soil, the best plant for the purpose is a leguminous shrub, Flemingia congensis. *It has extremely deep roots and does not compete with the surface roots of the citrus as does* Pueraria, *for example. If left unpruned,* Flemingia *would reach a height of 3 metres, or perhaps more. Here it is grown in hedges and kept pruned. The freshly pruned shoots make ideal material to mix with old banana plants, elephant grass, and similar residues in the compost pit.*

Photos by Charles E. Kellogg

Photo No. 37. Chestnut soils developed under grassland in the semi-arid temperate region of western North Dakota, U.S.A. The deep smooth-lying Chestnut soils may be used for cereals under dry farming, but the more rolling ones should be used for grazing. Here beef cattle are being grown with properly controlled grazing. Ordinarily, these soils do not respond to fertilizers under dry farming, although some of them require phosphate. Under irrigation, they usually respond markedly to phosphate and generally to nitrogen. Phosphorus deficiency of herbage is sometimes a problem with cattle, but it can usually be met more economically by supplemental feeding than by fertilization of the range.

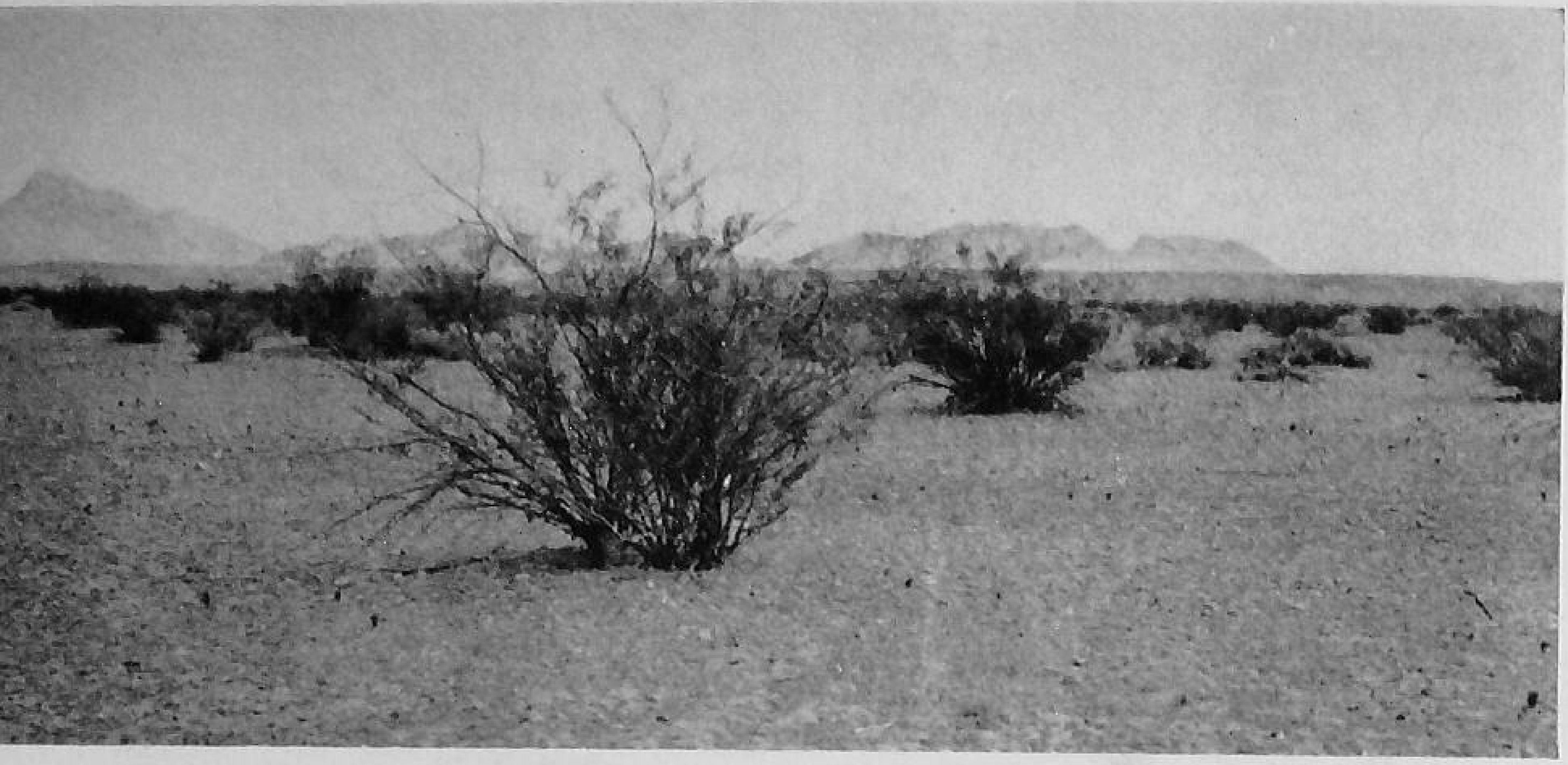
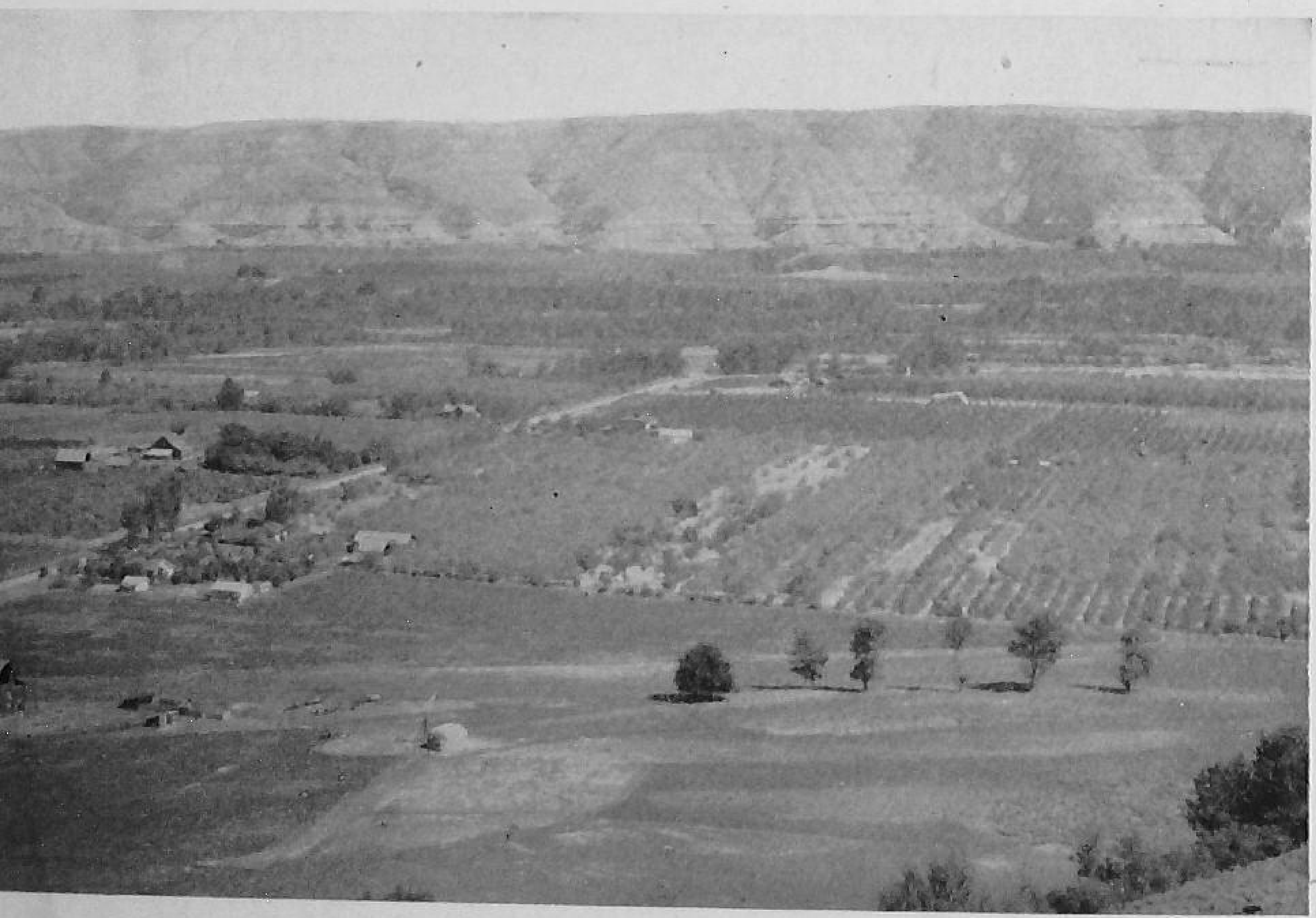


Photo No. 38. Characteristic desert soil with widely spaced desert scrubs and fairly well-developed desert pavement in southern Nevada, U.S.A. (approximately 18 centimetres of rainfall). Many desert areas have even less precipitation and are nearly devoid of vegetation. Soils of the deserts are generally well supplied with mineral nutrients, but are low in organic matter and nitrogen. Often phosphate fertilizers are needed. In many places harmful concentrations of salts are present. Irrigation is required for crop production.

Photos by Charles E. Kellogg.

Photo No. 39. Irrigated desert soil in the Naches Valley, Washington, U.S.A. The principal crop is apples. Phosphorus, nitrogen. and occasionally even potassium fertilizers are used, depending on the crop. Iron chlorosis is sometimes a problem.



shade, their fallen leaves and prunings are incorporated in the soils as green manure, and their deep root systems improve soil drainage and fix some nitrogen, which ultimately becomes available to the tea. In the Assam tea district of India annual legumes like *Mati-kalai* (*Phaseolus mungo*) have been used rather extensively.

In Ceylon, green manuring has been used for tea and other crops. In Java a leguminous deep-rooted shrub, *Tephrosia candida*, among others has been used effectively for green manuring in tea, coffee, and rubber plantations. A common practice is to plant it between the rows of tea plants and to cut it several times a year, the loppings being buried or used as mulch around the tea. In Java, also, annual and perennial creeping plants are used in tea, coffee, rubber, oil palm, cinchona, and sisal plantations. Among these green-manure crops are *Indigofera endecaphylla*, *Vigna hosei*, *Calopogonium mucunoides*, *Mimosa invisa*, and *Shuteria vestita*.

In Puerto Rico, such green-manure crops as cowpeas, jack beans, velvet beans, pigeon peas, and wild legumes are used in citrus groves. These contribute to the organic matter of the soil, which under the prevailing conditions rapidly decomposes, with consequent deterioration in soil structure and soil productivity.

In the Low Congo the shrubby legume, *Flemingia congensis*, makes an excellent companion crop for citrus on heavy soils, partly because of its deep root system. The freshly cut trimmings make excellent material for the compost (see photo No. 36).

These brief remarks on green manuring in the tropics serve as a reminder that the best use of land has to be worked out in each area. Except for experimentation, there is danger in attempting practices not yet tested for local conditions.

Crop Residues

Crop residues of all kinds, including roots, straw stalks, potato tops, and beet and vegetable tops are valuable for maintenance of soil fertility and as a source of organic matter and plant nutrients. All these residues can be ploughed back into the soil to save the plant nutrients, which would otherwise be lost to succeeding crops.

Crop residues are usually used most efficiently on farms where stock is kept. They provide feeding or bedding for the animals, and the manure, with the bedding, is returned to the land. Pasture crops in a rotation are consumed on the land and little or no residue is removed, depending on how animals are handled at night.

When livestock is not kept, crop residues can be composted before being incorporated with the soil or they can be directly ploughed under. However, incorporation into the soil of large quantities of

highly carbonaceous organic material such as straw may have a depressing effect on the yield of the subsequent crop, since the micro-organisms increase and compete with the plants for nitrogen and extra water.

Crop rotation and the use of fertilizer and manure cannot be substituted for one another. Best crop production is obtained when these practices are used together in a system adapted to the local soil type. However, where chemical fertilizers are scarce or unavailable, crop yields can be maintained or increased by adopting better rotations, by making full use of animal manures and crop residues, and by using lime and green-manure crops when necessary.

In fact, fertilizers by themselves are wasteful on farms that do not have a good cropping system.

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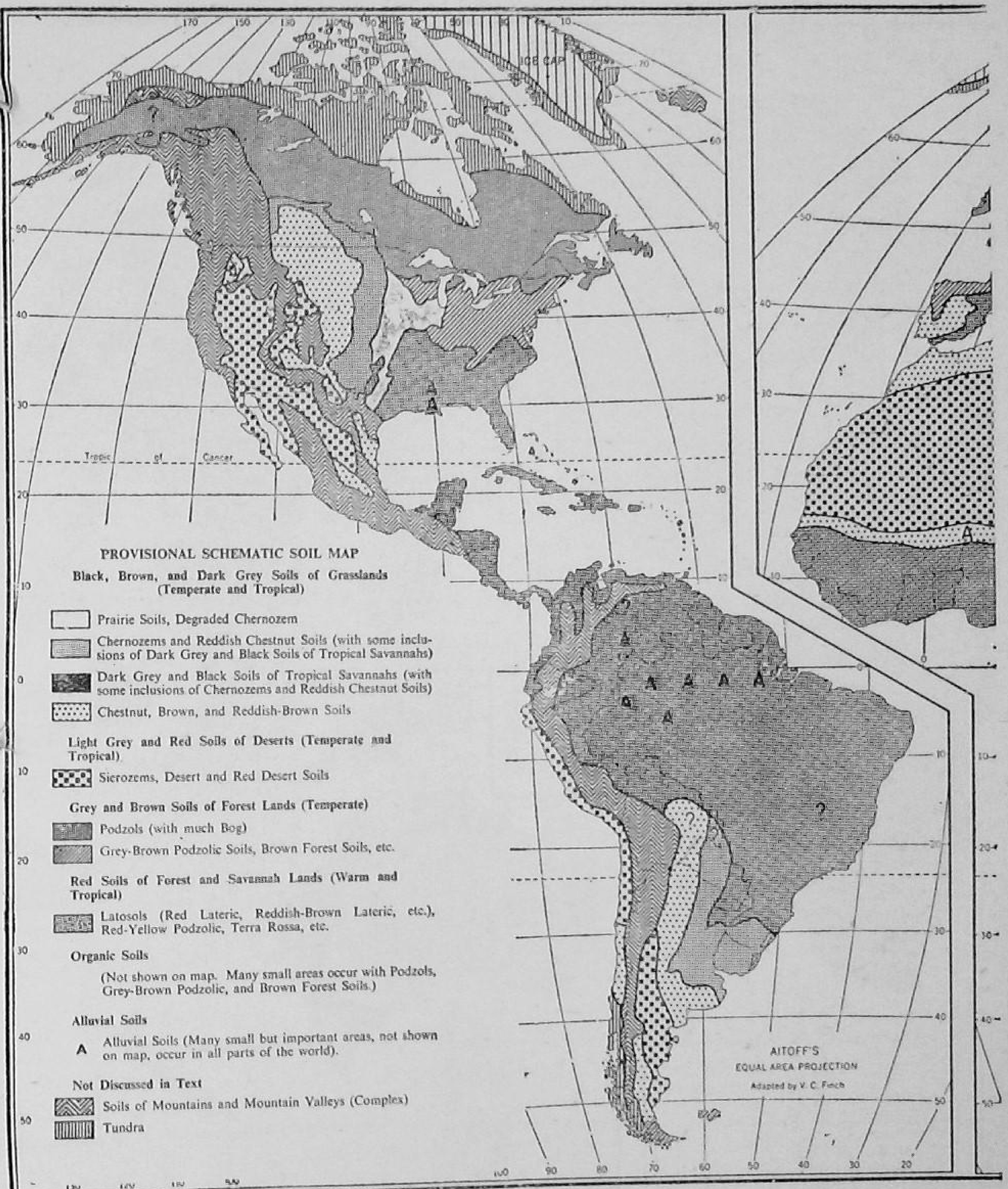
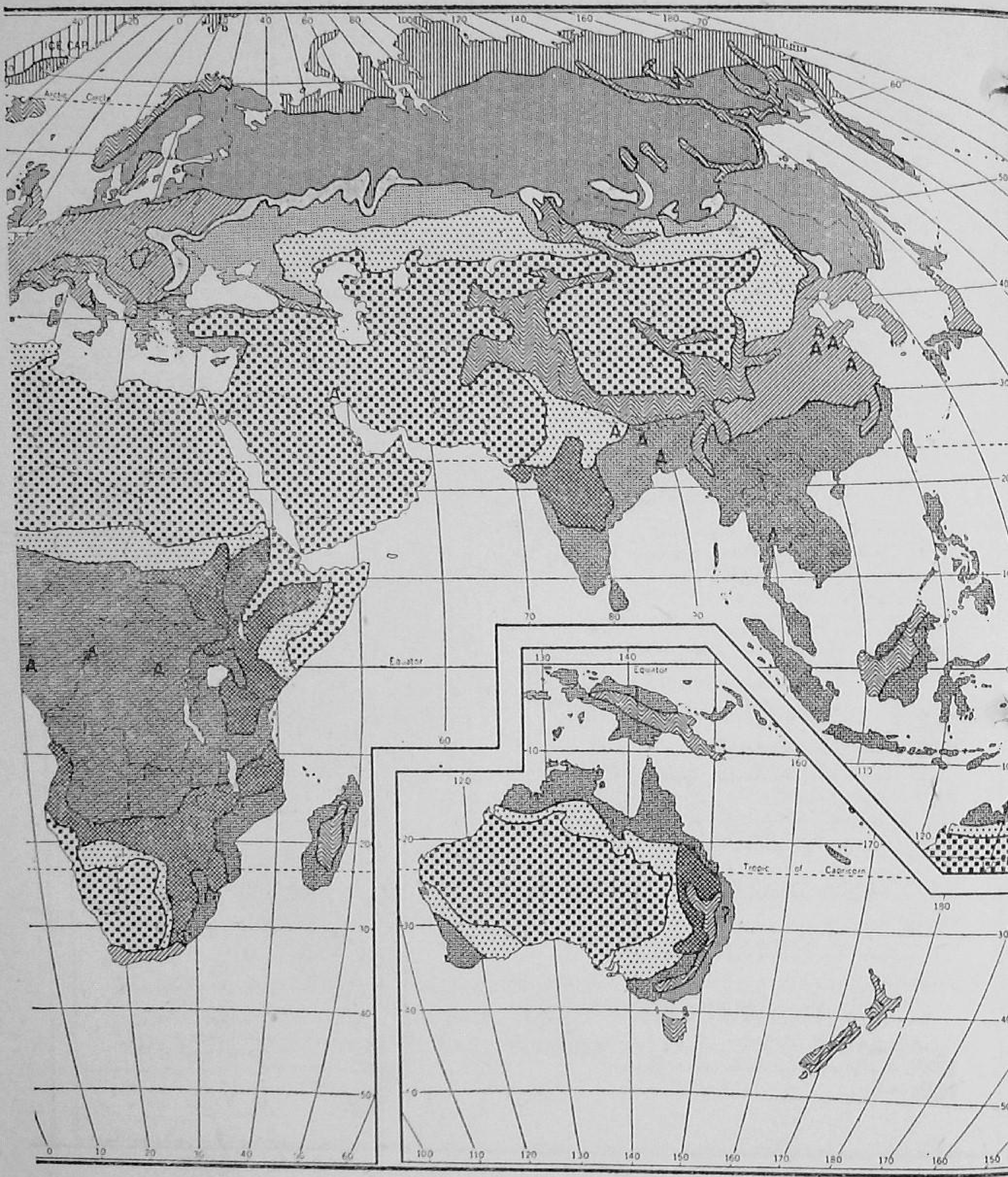


For further notes see pages 123–24.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Tropic of Capricorn

FURTHER NOTES ON SOIL GROUPS SHOWN IN MAP

BLACK, BROWN, AND DARK GREY SOILS OF GRASSLANDS (TEMPERATE AND TROPICAL)	*Prairie Soils, Degraded Chernozems, etc.*: Prairie soils: very dark brown or greyish brown in the surface, grading into slightly heavier brown material in the subsoil; slightly leached; high in fertility; high in productivity. Degraded Chernozems: wooded associates that are more leached. They have a thin organic layer underlain by a grey leached layer over a dark brown, heavier subsoil. Natural fertility, medium. Productivity high if adequately fertilized.
	Chernozems and Reddish-Chestnut Soils: Chernozems: black soils high in humus to a depth between 45 and 90 cm. with a lime accumulation below; granular structure; high in fertility; medium to high in productivity, especially for grains. Reddish-Chestnut soils: differ from Chernozems in being reddish-brown and somewhat lower in organic matter. May respond to phosphate fertilizer and in some places to nitrogen, especially on maize.
	Dark Grey and Black Soils of Tropical Savannahs: Soils low in humus even though dark in colour; mainly clays that crack deeply upon drying and, in many places, are self-mulching; medium in productivity without irrigation, high with irrigation. Require nitrogen fertilizers.
	Chestnut, Brown, and Reddish-Brown Soils: Soils of grasslands varying mainly in colour, as the names indicate, and in depth, over lime accumulations in the lower subsoil; medium content of organic matter; high in plant nutrients; low in productivity without irrigation, high with irrigation. When irrigated, respond to nitrogen and phosphorus fertilizers.
LIGHT GREY AND RED SOILS OF DESERTS (TEMPERATE AND TROPICAL)	*Sierozems, Desert, and Red Desert Soils*: Grey or red soils generally high in lime and mineral plant nutrients; dominantly either deep and sandy or shallow and stony; very low in productivity without irrigation; high with irrigation. Many areas of salty soils are included. When irrigated, phosphorus and nitrogen fertilizers usually needed for best yields.

GREY AND BROWN SOILS OF FOREST LANDS (TEMPERATE)	*Podzols (with much Bog)*: Podzols: organic layer about 5 to 10 centimetres thick underlain by a light grey, highly leached layer over a brown subsoil; mainly in forest; natural fertility generally low; productivity usually low unless lime and fertilizer are used and legumes grown in rotation. Bog soils: poorly drained peats and mucks.
	Grey-Brown Podzolic Soils, Brown Forest Soils, etc.: Grey-Brown Podzolic soils: thin organic layer underlain by a greyish-brown or yellowish-brown leached layer over a brown subsoil; medium fertility, medium to high productivity when proper amount of lime and fertilizer are used, along with manure or compost and legumes in rotations. Brown Forest soils: lack the greyish or yellowish subsurface layer, and are somewhat more productive naturally.
RED SOILS OF FOREST AND SAVANNAH LANDS (WARM AND TROPICAL)	*Latosols* (*Red Lateritic, Reddish-Brown Lateritic, etc.*) *Red-Yellow Podzolic, Terra Rossa Soils, etc.*: Latosols: wide group of red leached soils including the highly friable "Red Loams" of tropics; high in iron and aluminum, low in silica and bases; low in plant nutrients; high fixers of phosphorus; medium to high in productivity if adequately fertilized. Red-Yellow Podzolic soils: intermediate in chemical composition between Latosols and Grey-Brown Podzolic soils; highly leached; light grey surface soil over red or yellow subsoil; low in plant nutrients; fairly high fixers of phosphorus; low in productivity without fertilization, medium to high with fertilization. Terra Rossa soils: red, relatively unleached soils over limestone, mainly in Mediterranean region; fairly high in plant nutrients, fairly high fixers of phosphorus; medium to high in productivity under good management.
ORGANIC SOILS	Not shown on map. Many small areas occur with Podzols, Grey-Brown Podzolic, and Brown Forest soils.
ALLUVIAL SOILS	Not delineated on map, but principal areas indicated by "A." Many small but highly important areas occur in all parts of the world.
SOILS NOT DISCUSSED IN TEXT	*Soils of Mountain and Mountain Valleys* (*Complex*): Soils vary widely depending largely on climate and vegetation, but soils on mountains are generally shallow and stony; in the valleys, deep and non-stony to moderately stony.
	Tundra: Dark brown peaty layer over greyish horizons mottled with brown. Lower substrata very cold or ever-frozen. Very little used for agriculture.

Photo No. 40. Dense spruce forest on Podzol in New Brunswick, Canada, south of Richibucto. Although ill-adapted to most farm crops in their natural state, these soils can be made productive through the use of lime and mineral fertilizers and the introduction of legume hays and pastures. (Exposure time on this picture was 20 seconds.)

Photo by Charles E. Kellogg.

Photo No. 41. Rain forest of warm and tropical forested lands. Although soils of such lands support a luxuriant natural vegetation, productivity after clearing may decline rapidly or remain high, depending on management. Sustained high productivity requires frequent applications of fertilizers, including elements required by plants in small quantities and sometimes lime. In addition, mixed cultures, shading, and mulches are highly important. Red Latosol soil near Luki, Belgian Congo.

Photo by Charles E. Kellogg.

VII

PLANT-NUTRIENT RELATIONSHIPS TO SOIL REGIONS

CLIMATE leaves its impress upon the natural vegetation and upon the soil. Under natural conditions the humid lands of the earth are woodlands, the dry lands are desert shrub or waste, and the zones of intermediate moisture supply are grasslands. The soils that have developed under the forests and in the deserts of the world differ from each other and have different plant-nutrient requirements.

In addition to these broad zones are the local areas of Organic and Alluvial soils. Alluvial soils are those in the present flood plains of streams which, within recent times, have occasionally flooded. These soils have less in common with each other than the other groups, yet they are a distinct group in some features that affect nutrient relationships. The Organic soils—peats and mucks containing a large proportion of organic matter—occur in the more humid regions, usually in depressions associated with the soils developed under grass and especially forest.

Within each of these broad groups, of course, are many local types. Since these differ in many features that affect soil fertility and nutrient supply, only broad generalizations can be made; and to general truths about each group there are many local exceptions.

BLACK, BROWN, AND DARK GREY SOILS OF TEMPERATE AND TROPICAL GRASSLANDS

Some natural grasslands, such as marshes and well-watered prairies, occur in humid regions. They are far less extensive, however, than the grasslands which occupy wide sub-humid regions, such as the Great Plains of North America (see photo No. 37) and the Eurasian steppe, and part of the wet-dry tropical savannahs, such as north-western India and south-western Anglo-Egyptian Sudan.

Soils that have developed under temperate sub-humid grasslands are generally better supplied with plant nutrients than those of the other great plant zones. The heavy dark soils of wet-dry tropics are similarly well supplied, except that they are lower in organic matter. Because the rainfall is fairly light, leaching of nutrients is less severe than in forested regions. Lime tends to accumulate in the subsoil instead of leaching away. The grasses feed heavily on lime; as they

die and decompose they return it to the surface layers and lime is rarely needed on these soils. Organic matter and nitrogen, particularly in the more nearly humid grasslands where the grass grows taller and thicker, are relatively high.

Lack of moisture, more often than lack of plant nutrients, limits crop yields on these soils. In years of average rainfall, and more especially in drier years, the use of fertilizer may bring little or no response because there is not enough moisture to make the added nutrients available to plants. In years of heavy and well-distributed rainfall, however, or with irrigation, crops may benefit from added nutrients. Under these conditions phosphorus is most likely to be needed by soils of temperate grasslands and nitrogen by the dark heavy soils of the tropical savannahs.[1]

In these regions, with their predominantly dry climate and soils high in lime, rock phosphate becomes available too slowly. More soluble sources of phosphorus are needed.

With cultivation and crop removal, the organic matter no longer accumulates in the soil as it did under natural grass. On fields that have been cultivated for a long time, nitrogen may be needed, especially for crops which have a high requirement for nitrogen, such as maize. The soils in most places are likely to be well supplied with potash and with those nutrients required in small quantities.

In some low places, where water stands after rains or where there is ground water close to the surface, salts may accumulate in amounts harmful to crop growth, especially in the drier parts of the grasslands. Such accumulations are less common in the grasslands, however, than in desert regions. Injurious salts accumulate in many irrigated areas where good drainage is not provided. If the soil contains too much salt, leaching alone can correct this unfavourable condition, unless the salts include a high proportion of sodium. In the latter case leaching may make the soil nearly impermeable to water and difficult to till. Correction of this unfavourable condition requires the application of gypsum or sulphur, followed by leaching. Good drainage, which is difficult at best, is necessary for leaching.

Light Grey and Red Soils of Temperate and Tropical Deserts

Lack of moisture is, of course, the principal limiting factor to plant growth in the desert (see photos Nos. 38 and 39). Desert soils are generally well supplied with all the plant nutrients except nitrogen, although under heavy cropping phosphorus is often needed. Mineral nutrients under natural conditions are not lost by leaching. Because

[1] The soils of the Union of South Africa are exceptionally poor in phosphorus, and supplementary feeding of livestock with bone meal or other assimilable phosphate is usually found necessary and cheaper than fertilizing the veldt (the natural grazing land).

desert soils support only a sparse vegetation, little organic matter and consequently little nitrogen accumulates in the soil. Nitrogen deficiencies are usually the first to be met in cultivating irrigated desert soils.

Phosphorus may be needed in some places after the demand for nitrogen has been met. The more soluble sources of phosphorus such as superphosphate are needed; in these dry climates and on soils so high in lime, rock phosphate supplies phosphorus too slowly to be of much help.

Desert soils frequently have an excess of soluble salts. These are most commonly found in low places from which the water does not drain quickly after rains and in soils receiving seepage of irrigation water. After adequate drainage is assured, leaching of the excess salts is needed to permit successful cropping.

In many places desert soils are too alkaline for good plant growth. In other places they may become highly alkaline when irrigated if there is too much sodium in the salts present in the soil or in the irrigation water. Reclamation of such soils requires good drainage, the application of sulphur or gypsum, and leaching with water low in sodium.

Often crops on desert soils high in lime exhibit chlorosis or loss of green colour. This condition is believed to be related to lowered intake of iron in alkaline soils. Its correction is difficult, but a possible remedy appears to be the reduction of alkalinity by the use of sulphur or of acid-forming fertilizers such as ammonium sulphate. Spraying with iron sulphate solution has also proved effective.

Grey and Brown Soils of Temperate Forests

Forests grow in the earth's more humid regions (see photo No. 40). With high rainfall the soils that have developed under the forest vegetation are generally leached of soluble nutrients and lime. The total content of organic matter in these soils is high, but the content of partially decomposed organic matter, called humus, is usually less high than in the soil of temperate grasslands. People sometimes think that a forest soil must be rich. As a rule, however, forest soils, when used for cultivation, need organic matter, lime, and mineral nutrients, including in some places those elements required by plants in small quantities.

The soils of forest regions are generally, but not always, too acid for best growth of most farm crops, particularly grasses and legumes. Liming is usually the first requirement, but these soils vary in their need for lime, and on a few soil types of the Temperate Forests no lime need be applied. There are simple and dependable soil tests to find the degree of acidity and help estimate the quantities of lime

needed. In general, sandy soils require a smaller application to reduce the acidity by a given amount than fine-textured soils such as clays or clay loams. In addition to its function in reducing acidity, lime is also needed to assure reasonably efficient use of phosphate fertilizer. Phosphorus applied to strongly acid soils becomes fixed and unavailable to plants.

Next to lime, nitrogen is most commonly needed on these soils, followed by phosphorus and potassium. In many places, particularly on sandy soils, some of the other elements—boron, manganese, zinc, calcium, magnesium, or iron—may be deficient. Use of liming materials that are, in part at least, dolomitic (containing magnesium) helps to assure an adequate supply of magnesium in addition to the necessary calcium.

Of greatest importance in fertilization are the minerals—calcium, phosphorus, potassium, and the like. Nitrogen supplies can be maintained wholly or partly through the growth of legumes and the conservation and use of animal manure. The latter is needed anyway to maintain a good supply of organic matter in the soil. Often some commercial nitrogen is necessary, but in a good farming system it should never be used as a sole source of nitrogen but should supplement the legumes and animal manure. If organic matter is allowed to diminish, the soil deteriorates physically from loss of structure and there is danger of damage from soil erosion. Since these soils tend to lose plant nutrients rather rapidly by leaching, careful attention must be given to the rate and timing of fertilizer application. If more of the soluble nutrients are applied at one time than the crop can quickly use, part of the fertilizer may be lost by leaching before the crop can benefit. Fertilizers must be placed so that they are readily reached by plant roots at different stages of growth. In row crops, for example, it is often more efficient to place some of the fertilizer in bands (in the rooting zone, alongside the rows), where it is soon reached by the roots of the young plants.

In forested regions where the soils are generally deficient in all the principal plant nutrients and where the climate permits a great variety of crops to be grown, care must be taken to secure a proper balance of nutrients. This balance has to be determined by experimentation on the different kinds of soil. Adequate trials by public organizations or institutions save farmers the expense of experimenting on their own lands.

Red Soils of Warm and Tropical Forests and Savannahs

The extensive red soils under forest or savannah in warm or tropical climates are generally highly leached of soluble plant nutrients (see

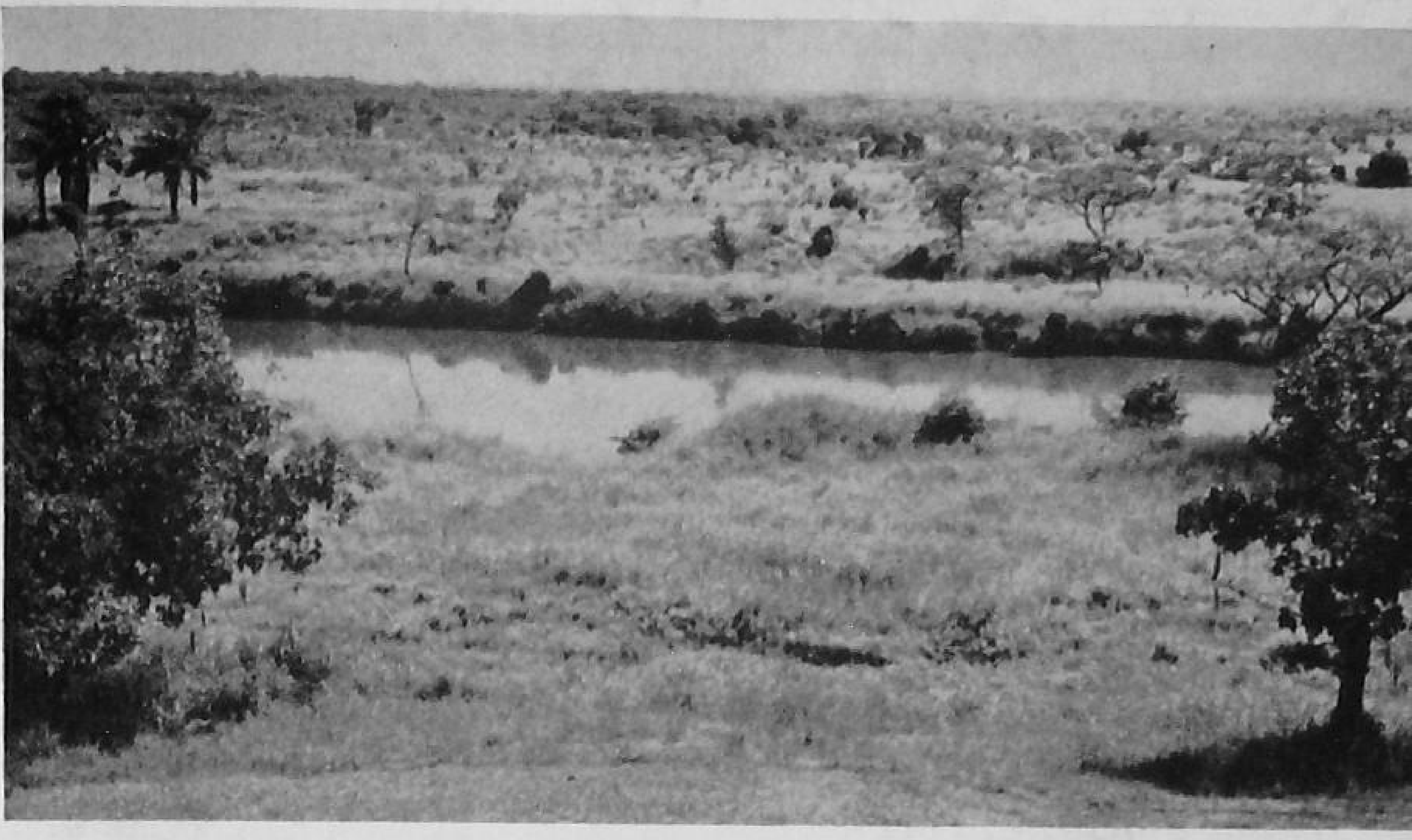

Photo No. 42. Savannah area in a warm and tropical region. Grasses generally attain a height of several feet; scattered shrubs and trees are common. The soils of tropical grasslands ordinarily require fertilization for best crop production. Near Gangala na Bodio, Belgian Congo.

Photos by Charles E. Kellogg

Photo No. 43. Intensive production of beans on good muck soil in Florida, U.S.A. Protective banana plants and palms in the background. Organic soils, formed from many different kinds of vegetation, occur in most of the soil regions of the world. Almost universally, they require artificial drainage and fertilizers, including potassium and phosphorus. Some also require lime and other fertilizers, including those elements which are required by plants in small quantities, especially copper.

Photo No. 44. Very acid muck soil, productive for cranberries with proper fertilization and precise water-table control. Massachusetts, U.S.A.

Photo by Charles E. Kellogg.

photos Nos. 41 and 42). The areas occupied by these soils in tropical and equatorial regions have had few soil surveys. It is known that other soils occur mixed with them, such as highly productive young soils from recent volcanic deposits and old, relatively infertile soils of the undulating plains, and that there are important subdivisions. When detailed soil surveys are available for the world, a larger number of local soil types will probably be found in these regions than elsewhere. It can be said now that these soils are usually more thoroughly leached than the soils of temperate-zone forests and have less capacity to prolong the good effects of fertilization. Plant nutrients are retained mainly by the organic matter of the soil, and this decomposes rapidly when the soil is exposed by cultivation. It is advisable, therefore, to preserve the organic matter by shading the soil, by using cover crops and green-manure crops, by growing perennial deep-rooted grasses, or by bringing organic matter from elsewhere to replace what has been lost. Unless this is done, all mineral nutrients are likely to be needed.

Liming to correct acidity is sometimes needed on these soils, but less lime is required to reduce acidity a given degree than on most soils of the temperate forested regions. Phosphorus tends to become fixed quickly in the non-organic part of the soil and is then less available to plants. Judicious liming to reduce acidity and the addition of organic manures to improve the organic status of the soil help somewhat to lessen this tendency.[1] The great need for phosphate fertilizer to help establish leguminous cover-crops in the humid tropical regions, especially on acid soils, is stressed by a number of authorities.

Because of the high rate of nutrient loss through leaching, special attention must be given to rates and frequency of application and to placement within reach of plant roots. For success with fertilizers, such use as is needed must be made of crop rotations, mixed cultures, shading, mulches, and other essential soil-management practices.

Proper balance among the plant nutrients is especially important. When lime, nitrogen, phosphorus, and potassium are used in large quantities, deficiencies of other elements may quickly become evident because of the increases in crop yields and a consequent greater draft on plant nutrients.

The fertilization of humid-tropical tree crops, such as cacao, coffee, citrus, and rubber, presents difficult problems which have not yet been solved in all cases. The complexity of these problems is increased by the differences in soil fertility caused by the variation in the length of

[1] The degree of weathering of soils under hot humid conditions, with a loss in silica content and a consequent increase in iron and alumina, is more important in fixation of phosphorus than the degree of acidity.

time since the felling of the original forest and by differences in the extent to which use is made of shade trees either planted or left over from the original forest. Whereas freshly cleared forest soils are generally rich in nitrogen, those that have first been exploited for growing exhausting food crops are usually deficient in nitrogen because the initial litter has all decayed. Succeeding tree crops, such as cacao, can then be established satisfactorily only by the aid of nitrogen fertilizers. The planting of leguminous shade trees as a canopy for cacao or coffee obviates this necessity by providing bacterial nitrogen, but the trees grown under shade seem to require more potassium, presumably to compensate for the diminished sunlight.

Organic Soils

In their natural state organic soils are nearly always poorly drained. For most farm crops, artificial drainage is needed before much benefit can be expected from fertilization.

Organic soils are nearly always deficient in potassium and phosphorus, especially the former, and very frequently in some of the elements such as copper, manganese, zinc, and boron (see photo No. 43). These soils vary widely in acidity. Some need no additional lime, while others need a great deal unless acid-tolerant crops such as cranberries are grown (see photo No. 44). More lime is usually needed in an organic than in a mineral soil to reduce the acidity by a given degree. A heavy application of lime, bringing about a large reduction in acidity, may create deficiency symptoms, for example of boron, because of decreased solubility of salts of some of these nutrient elements as soil reaction becomes neutral or alkaline (see Chapter II).

Although the nitrogen content of Organic soils is high, the nitrogen is not always in a readily available form in sufficient quantities for the best growth of some plants—for example, vegetables in which succulence is an important quality. This is especially true if the soil has been cultivated for several years. Under these circumstances, plants benefit from additional nitrogen as well as the necessary mineral amendments.

Alluvial Soils[1]

Alluvial soils are enriched by plant nutrients carried and deposited by flood waters. These soils are generally more fertile than the upland soils of the watershed and generally have less of the nutrient defi-

[1] Alluvial soils are those youthful soils of the flood plains receiving materials from at least occasional overflow. The term is not the same as "soils from alluvium." Soils from alluvium with developed characteristics are called Podzol, Chernozem, Latosol, or whatever name is appropriate to their morphology.

cies common in the regions from which the sediments were derived. For instance, although phosphorus deficiency is acute in the residual soils of the Union of South Africa, the Alluvial soils usually have such an ample supply of available phosphate that even after twenty or thirty years of intensive cropping—for example, to lucerne—phosphate fertilizers are not yet used.

(1) Alluvial soils of a forested watershed are likely to need some lime. Some are very acid and give excellent response to applications of lime; others are not. For example, upland soils developed from limestone may be strongly acid while the associated Alluvial soils are not.

In addition to nitrogen, phosphorus, and potassium, small applications of boron, manganese, zinc, calcium, magnesium, and iron may be needed.

(2) Alluvial soils of streams draining grassland watersheds, mainly in the temperate zones, are likely to be in no great need of fertilizer elements, but in many places these crops respond significantly to phosphorus and nitrogen.

(3) Alluvial soils of deserts are likely to need nitrogen and, to a lesser degree, phosphorus. In many places, after good drainage has been assured, excess salts need to be removed by leaching, and, following applications of sulphur or gypsum, excess alkalinity needs to be corrected by leaching.

(4) Alluvial soils of the humid tropics are likely to need both phosphorus and nitrogen. In some cases, rock phosphate has proved as good as superphosphate. For highly acid soils, additions of lime or of dolomitic limestone should be tried. As in the case of Organic soils, heavy applications of lime may cause deficiencies which were not previously present.

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[1] Reports of well-conducted field experiments everywhere are valuable in gaining an understanding of the individual fertilizer responses of soil types and great soil groups, where the names are given or can be discovered. For a list of 594 references to work in the United States, see: McNeill, John M., *Fertilizer Use and Crop Yields: A List of References.* (USDA Library List No. 27) Washington, D.C.: United States Department of Agriculture, July 1946. Pp. 67.

VIII

THE FARMER AND THE AGRICULTURAL SERVICES

It can be said that five systems normally operate on a farm: the water system, the system governing organic matter, the tillage system, the cropping system, and the fertilizer system. A sixth—the liming system—may also be necessary if operation on acid soil is included. All of these systems are interdependent and some are very closely inter-related. The success of the farm depends upon how well they are managed.

Questions of Soil Management

Extension workers and agricultural advisers in countries where the work of aiding farmers is well organized realize that the alert farmer, consciously or unconsciously, is always asking himself how well he is managing these systems. They have learned that the best technique in agricultural assistance is to get the farmer to formulate his queries. Once he has done this, he will not rest easy until he has found the answers—from his own resources, from his neighbours, or from technical consultants. The following sets of questions are samples of those the farmer can be encouraged to ask.

WATER

Am I putting irrigation water on my crops in the right amount and at the right time?

Do my soils absorb water readily, either from rain or irrigation?

Are my fields properly drained?

Is there much run-off?

Does it make gulleys or wash the sloping fields?

Are the gulleys increasing in size and number?

Are some fields more erodable than others?

Do any of my fields "blow"?

If he answers these questions correctly, the farmer knows whether water is a limiting factor in his crop production. If it is, he must be forced to ask, "What can I do about it?" and find the proper answers.

LIMING

Do I have acid soil?

Has it been limed in the past?

Do my neighbours lime their soils?

How much lime do I need?

Tests for soil acidity with the "indicators" mentioned in Chapter V are very simple from the standpoint of the technician, but they require a certain amount of technical understanding, and not every farmer can make and interpret them successfully. A number of farm crops do not grow well on strongly acid soils, and most legume crops are particularly sensitive to high acidity. Most farmers do well to seek technical advice on this problem. In certain dry regions, of course, the problem is one of reducing alkalinity by the use of gypsum or sulphur or by other methods.

ORGANIC MATTER

Are my soils well supplied with organic matter?

Do I use enough manure?

Do I make efficient use of crop residues by composting and turning them under?

A farmer may have little or no knowledge of the organic content of his soils, because with many soils it is impossible to guess even roughly by a cursory inspection. But any farmer should have a clear idea of how much organic matter he is returning to the soil.

TILLAGE

Do I prepare a good seed-bed?

Do I seed at the right time?

Is my land weedy?

Correct answers to these questions indicate whether conditions most favourable to seed germination and crop growth have been provided. Plant-nutrient deficiencies are often blamed for poor crops when a variety of other causes may be responsible. For instance, a poor seed-bed can result in poor and uneven germination. Seed planted too late can prevent crops from getting properly established before a spell of dry weather. Or, too great competition from weeds can retard crop growth.

CROPPING

Do I have the best proportion of tilled crops to pastures?

Is my rotation the most satisfactory for crop production and improved fertility?

What crop sequence gives me best results?

What results do I get on later crops after ploughing under legumes?

Am I using the best-yielding varieties of crop plants for my area?

Am I using the following methods of disease control: treating the seed, growing disease-resistant varieties, avoiding the too frequent planting of susceptible crops on soils that seem to encourage the disease?

These questions, if properly answered, indicate whether a particular cropping system would help to improve soil productivity and whether the best available plant materials are being used. Unless strong-growing, high-yielding, and disease-resistant varieties are used, good crop production cannot be expected, however adequate the cultural and fertilizer practices may be. Some of these questions the farmer can answer for himself on the basis of his own experience or by comparing his practices with those of better farmers in his neighbourhood, but considerable technical knowledge is needed to answer others.

FERTILIZER

How do my yields compare with those of the best farmers in my neighbourhood?

Which are my most productive fields?

How do they differ from those less productive?

Is there particularly good plant growth around the droppings of animals?

Does the soil show particular response to the use of wood ashes?

Are any of my crops stunted in their growth?

Do they have a good healthy colour or are they yellow-green?

Could these conditions be caused by poor soil preparation or lack of water?

Are my farm animals thrifty?

Do any of them show unnatural appetites, such as licking and eating bones?

The answer to each of these questions must evoke the further question, "Why?" The need for fertilizer is indicated if there is, by comparison, exceptional growth of plants around the droppings of animals. Yellow-green coloration of crop plants which cannot be attributed to lack of water is an indication that nitrogen, at least, is deficient in the soil. A similar colour, occurring in Australia, may also indicate a deficiency of molybdenum. If soil acidity is no problem, quick response to an application of wood ashes may indicate a need for potassium—or, in Australia, for molybdenum. Unnatural appetites among farm animals are often caused by a dearth of phosphates in the soil.

The farmer, on the strength of his own experience, can answer a number of these questions. The more experienced he is, the more correct his answers are likely to be. He can get a certain amount of information by comparing his soils, methods, and production results with those of his neighbours. But, useful as all this information may be, often it is not enough to enable him to select the best possible known practices which will provide the greatest return for his labours and still improve the fertility of his soil.

Assistance on Soil Management Problems

It is evident that even a good and alert farmer can go only so far on his own in planning the most efficient management of his soils, including the most efficient use of fertilizers. Some of his problems can be solved only with technical help. In most countries this help can be obtained through public services established for the purpose. In some countries, all or nearly all of the required services are in operation; in others, only some of them; in still others, for various reasons, there are no organized services to assist farmers with their soil-fertility problems, or the work has barely begun. Where few or none of the necessary services exist, their organization will require much time, money, and effort. The techniques employed by some other countries, briefly outlined below, may be helpful.

ASSESSING CROP REQUIREMENTS

Soil classification. Soil surveying and mapping are conducted in a number of countries. The detail with which this work is carried out varies from country to country and from area to area within countries.

As is well known, soils differ widely in their fertilizer requirements and in the way crops grown on them respond to fertilizer treatment. By classifying the soils, by conducting surveys and mapping the different soil areas, a systematic knowledge can be gained. Such knowledge is of great value in selecting the most suitable sites for

field experimentation. Where few or no soil surveys have yet been made, valuable information can be obtained by conducting field trials on soils representative of the area. For this purpose, even a rough soil classification is better than none. Failing even this, it is often practicable to delineate the major soil areas on the basis of local agricultural knowledge and experience. Field trials, if judiciously placed, can assist the soil surveyor by indicating the productivity of different soil types. Field experimentation should not wait upon a formal field survey but should be undertaken as soon as possible in order to assure the correct utilization of soil resources.

Once the soils have been classified and surveyed, not only has a better knowledge been gained of their properties, but it becomes possible to outline accurately the areas with similar soils and, hence, those likely to require similar management and fertilizer use. Different fields on the same farm and even parts of the same field may require somewhat different treatment because of minor physical and chemical variations and because of their management history.

As soil scientists throughout the world develop a common nomenclature, soil surveys will become increasingly valuable, because practices which have proved useful on certain soils of one country can then be tried with good chances of success on similar soils in other countries—always provided that climate, water supply, and other variables are taken into account.

Field experimentation. There are a number of ways of determining what fertilizers should be applied to what soils and crops, but the method of field experimentation, laborious and time-consuming though it may be, remains the most reliable (see photo No. 45). Field experimentation on principal soil types, including trials with animal manures, commercial fertilizers, and soil amendments, should be the basis of the soil-fertility programme of any country. These trials, whether conducted by agricultural colleges, experimental farms, or other organizations, are the first stage in the process of applying in practice the scientific research conducted in laboratories and greenhouses at the universities and other research institutions. They should be carried out in close co-operation with laboratories which, by analysing soils and crops, can help to interpret the field results. The importance of field trials has on the whole been widely appreciated; during the past century a great many countries have established such experiments (see photo No. 48). However, sufficient precaution has not always been taken to set up field trials on soils representative of the area. Other considerations than representativeness have taken precedence in the selection of some sites and the results would be misleading if used for wide interpretation.

In the last few decades significant advances have been made in the techniques of field experimentation, and more reliable results are being obtained. For instance, the necessity to repeat experiments at many centres, on different soil types, and over a series of growing seasons is now widely recognized. On some soils, it is true, a deficiency may be such that the crudest field trials can identify it and indicate the approximate amount of fertilizer needed. More often, especially if crops are fair to good, yield increases may not be so spectacular and recourse must be had to statistical analysis in order to determine the significance of results obtained by different treatments.

In addition to the more formal trials carried out on institutional fields, simple fertilizer tests on a large number of ordinary farms scattered over an area have great value. Such tests are particularly useful in places where little or no fertilizer has been used, because they indicate very quickly what crop responses can be had from fertilizer treatments on a variety of soil types. They can also be of considerable value as demonstrations.

In less developed countries the introduction of fertilizer may necessitate changes in cultural practices and the introduction of better crop varieties to derive the full benefit from the high soil productivity and better rotations. All these changes will require careful preliminary field experiments on the principal soil types. It is too frequently assumed by workers from advanced countries that the agricultural methods of under-developed regions are totally inadequate and can easily be improved. Quite often, however, indigenous agricultural practices depend upon principles which are not yet fully understood by scientists and need experimental analysis. Hasty conclusions have often proved to be wrong. Local methods may be quite rational under the circumstances in which they are used, and important improvements might be possible only by changing the general social conditions—a far more difficult task than the introduction of up-to-date agricultural techniques.

A number of methods quicker than field experimentation have been devised to determine the fertilizer requirements of crops on different soils. With soil classification as a base, these methods make it possible to extend knowledge gained on experimental fields to the fields of individual farms.

Vegetative tests. The pot-test method of determining fertilizer requirements has been used extensively (see photo No. 20). In this method, which is similar in principle to the field-plot test, soil is placed in pots of about 4-litre capacity. The soil samples are differently fertilized, each is planted to a suitable test crop, and the responses are carefully noted. This method takes time and work,

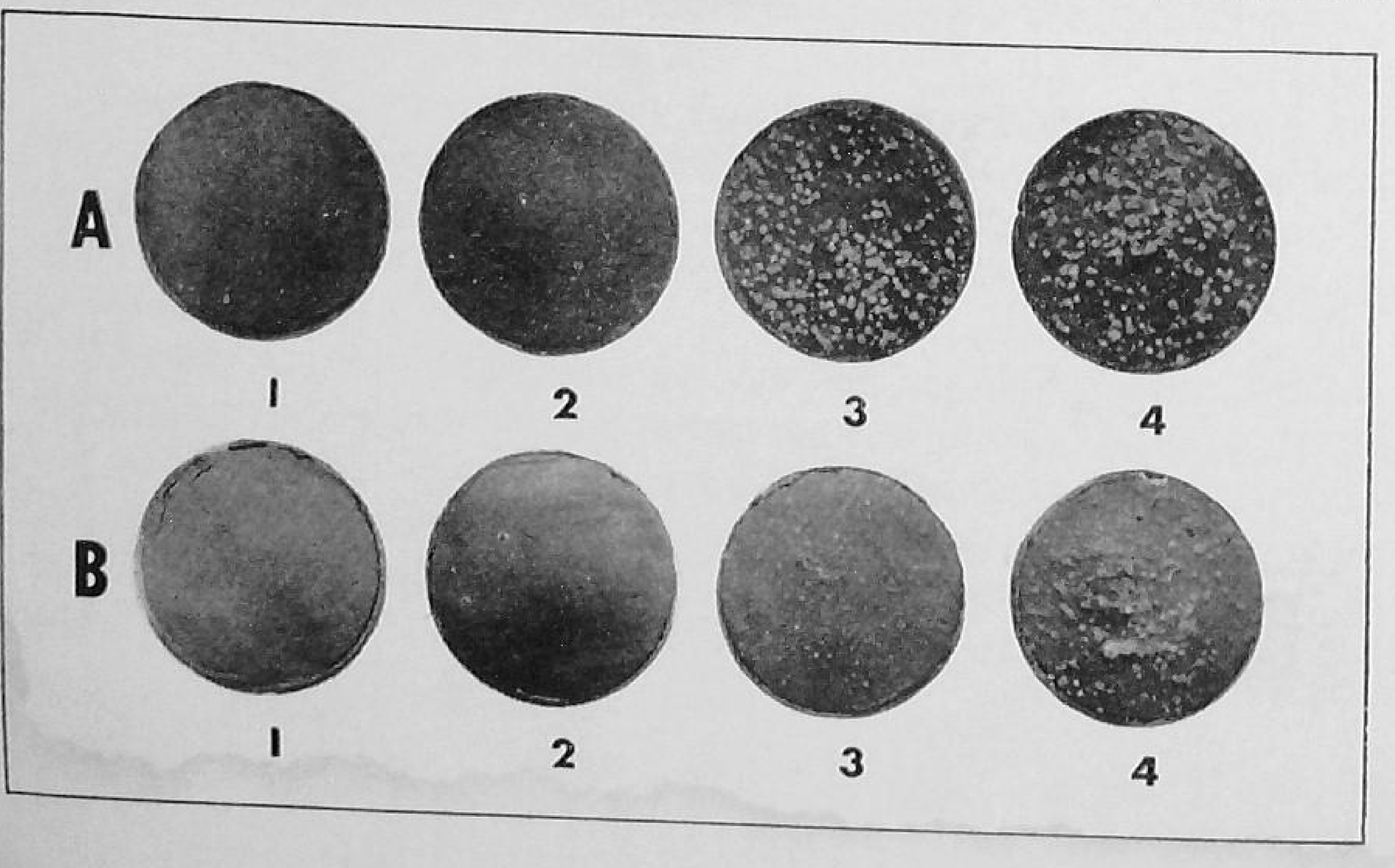
Photo No. 45. Experimental plots at the Central Experimental Farm, Ottawa, Canada.
Photo by courtesy of Central Experimental Farm, Ottawa, Canada.

Photo No. 46. Neubauer test. Rye seedlings at the end of a 17-day vegetation period, showing soil test on the left and check test on the right. The amount of plant nutrients extracted from the soil sample by such seedlings gives an indication of the available supply of these nutrients in the soil. Note the dark soil sample below the white washed sand in the glass vessel on the left.

Photo by courtesy of G. N. Hoffer.

Photo No. 47. Growth of Azotobacter on soil plaques. A. Soil very deficient in available phosphorus, not deficient in available potassium; B. Soil deficient in available phosphorus and potassium. (1) Check, nothing added; (2) potassium added; (3) phosphorus added; (4) phosphorus and potassium added.

Photo by courtesy of the Colorado Agricultural Experiment Station. Fort Collins, Colo., U.S.A.



but not so much as the field test; and when the tests are properly conducted, the results are fairly reliable. An essential difference between soil condition in the pot and in the field is that the potted soil becomes considerably warmer; as a result, there is greatly increased biological activity and even a change in physical property in the potted soil. These influences usually increase with time, and affect the validity of the results.

The Neubauer method, a simplified small-scale vegetative test which lessens the time and labour involved in the conventional pot test, has been used quite extensively, especially in continental Europe (see photo No. 46). Growth tests of certain species of bacteria and fungi on variously treated soil samples have also been used to a limited extent (see photo No. 47).

Quick tests. In recent years, chemical "quick tests" for the determination of the lime and fertilizer needs of soil have largely displaced vegetative and biological tests in many countries. In essence they are simplifications for rapid practical use of much longer and more exacting laboratory procedures designed to indicate available nutrients in the soil. Because of their speed and low cost, they make it possible to test several soil samples from each field on a farm. This is highly desirable because of the great variation in fertility that is possible in a single field. Development of more satisfactory quick tests has been greatly expedited by advances in analytical chemistry and a more exact knowledge of the forms of nutrient elements in the soil.

However, to be of value in estimating fertilizer requirements, any chemical soil analysis has to be calibrated against the results obtained in experimental fields, because the actual availability of nutrients in the soil depends on many factors beyond those involved in quick chemical tests. Furthermore, some of the quick-test procedures are none too reliable, especially in the hands of unskilled workers. Improved methods are still desirable and possible. They are, in fact, taking place every day.

Deficiency symptoms and tissue testing. Another method of diagnosing fertilizer needs is by means of the so-called hunger signs of plants which can be discerned with the eye (see Frontispiece). As described on pages 14-16, a decided lack of any plant nutrient usually results in the development of easily observed and rather specific abnormal colours, markings, and types of growth. Recognition of these symptoms is probably the oldest method of diagnosing fertilizer needs, for man undoubtedly at an early date correlated certain crop appearances with nutrient deficiencies and manure requirements. Much study has been given this subject in recent years and it is now

possible for one skilled in this field to make valuable diagnoses. Coloured illustrations of nutrient deficiency symptoms in various economic plants are available in pamphlets and books.

Useful as diagnosis by nutrient deficiency symptoms may be, however, it has certain drawbacks, which are discussed on pages 14–15. To overcome these handicaps, a plant tissue analysis can be quickly made for elements suspected of being lacking; these tests usually show a lack before surface symptoms appear.

Although much work has been done on tissue tests in recent years, no unanimity of opinion has yet been reached as to their value for determining the fertilizer needs of various crops on different soils and under different climatic conditions. They can be, however, of considerable local value. Those who use these tests stress the necessity of specifying the sampling methods and establishing the critical nutrient levels of crops under given conditions in order to obtain accurate results.

TAKING IMPROVED PRACTICES TO THE FARMER

Pilot farms and unit demonstrations. Many of the new methods growing out of agricultural research need to be modified and fitted into a pattern before they can be taken to the farmer. Pilot research farms provide a means for testing them under farm conditions. Such farms are analogous to pilot plants in industrial research.

The operations of the pilot research farm are planned and laid out by the scientists and are directed by a paid manager. The manager should be guaranteed an income at least as great as he would receive from independent operation. Additional equipment and materials are provided from research funds. Such farms should represent the principal combinations of soil conditions, types of farming, and size of farms in the test area. A definite relation of the pilot farm to others should be established by scientific correlation so that the results can be quickly used and generally applied. The records of the farm should be subject to exhaustive analysis by research workers.

Soil fertility and fertilizer practices tested on pilot research farms can also be used on demonstration farms. Upon the suggestion of extension and advisory people, some farmers may agree to try the improved practices on their own farms, with their own labour and capital (see photo No. 49). Such demonstration farms should also be selected so as to represent the principal combinations of soils, types of farming, and size of farms, and they should include both tenant-operated and owner-operated farms. There should be many demonstrations, enough so that every farmer can see one on a farm that resembles his own and is run by a man similar to himself.

On the pilot research farm decisions are made by a group of experts, but on the demonstration farms they should be made by the operator with technical assistance. Although plot demonstrations on an ordinary farm to teach one or more soil fertility practices have an undoubted value, the community probably derives greater benefit from a demonstration farm, a unit where all farm practices are fitted into a system.

The final step is the establishment of good soil fertility and fertilizer practices on all farms. Seeing for themselves the value of any of these practices, the farmers are much more likely to adopt them on their own farms.

Extension and advisory services. No matter how important the information may be that is gained from basic and applied research, field experimentation, soil surveys, pilot farms, and analysis of soils and crops, it remains sterile unless the farmers make use of it. And if farmers are to benefit from modern scientific knowledge, it must be brought to them, along with information on how best to apply it to their own problems. There has always been a time lag between developments of science and their application on ordinary farms. This is due in part to the conservatism of farmers, who generally are wary of new methods and practices, but it is also due to the failure of those in responsibility to realize that the farmer does not have easy access to the results of research. To apply scientific knowledge successfully, he generally needs advice and assistance. In the past few decades there has been a better understanding of these facts in many countries, and extension and advisory services have accordingly been established.

Scientific knowledge can be spread among the rural people in various ways. One of these is through state or farmer-sponsored extension services which supply agricultural advisers, agents, and counsellors to work with local farm organizations, committees, or groups of farmers. The advisers can arrange lectures, field days, and courses of instruction for farm groups, and demonstrations on farms can play an important role. It is much better for extension and advisory persons not to be connected with the agricultural regulatory activities of the government. The separation of these two functions makes for a better understanding between farmers and extension workers.

To widen the influence of the technically-trained advisers, local leaders can be chosen from the more progressive and more socially minded farmers. These leaders can be instructed in some particular phase of soil fertility and they can assist their neighbours. In countries where the rural population is literate, leaflets, bulletins, circulars, and

the agricultural press are media through which farmers can be informed of better soil-management methods. The radio and films also offer great possibilities for this purpose and have the advantage that their effectiveness does not depend on the literacy of the audiences.

By all these extension methods the farmer can become acquainted with improved practices, but he may still need advice on soils, crops, manures, and fertilizers on his own farm. Individual farmers should have the advice of trained agriculturists with a knowledge of soils and fertilizers who, in turn, should be able to consult soils specialists on the more difficult questions. Laboratory facilities for analysing farmers' soil samples should be available, for even the specialist often cannot foretell the fertilizer needs of crops on a particular soil by mere inspection of soil and crops.

The activities and services discussed in this chapter can be of value not only in countries with well-developed agricultural systems using large quantities of fertilizer, but also in less advanced areas far removed from industrial centres. It may be entirely impracticable at present to create indigenous fertilizer industries in such areas or to import expensive fertilizers for farmers operating at a subsistence level, but much can be done to increase crop yields by the better use of local materials such as animal manures, plant residues, wood ashes, and lime. The suggested activities could well be directed to this end.

How some countries help the farmer. A survey conducted by FAO on the methods used to furnish guidance on soil fertility and fertilizer problems has shown that many member countries are employing most of the types of services described. To be sure, the method of development, organization, and scope of these services and the extent to which they are used vary widely from country to country.

In most of the countries reporting, researches conducted in the universities, colleges, and institutions are tested in field trials. The amount and scope of field experimentation vary widely because of a great many factors, among them national differences in size, wealth, and general education. In different countries, also, the field work may be administered by different authorities—by central and local governments, by colleges and universities, by industrial organizations, or by private and public organizations. In the same country more than one authority may administer experimental work. In *Canada*, for example, there are agricultural colleges, largely provincially supported, in addition to the Dominion Experimental Farm System, comprising the Central Experimental Farm at Ottawa and a number of Dominion experimental stations and substations, administered by the Dominion Government.

In the *United States* the field experimentation on soil fertility is done principally by the state agricultural experiment stations as part of their agricultural research programmes. These stations are usually an integral part of the land-grant colleges. A few states have two more-or-less independent stations. Most states have substations, which work on special problems under control of the main station. The Congress has made various provisions from time to time for financial grants to the state experimental stations to supplement state funds, and Federal research scientists carry on work at these stations in co-operation with state scientists as part of a regional or national research programme. Federal scientists stationed in one state often have responsibility for work in a wide region that overlaps parts of several states. Much experimental work on problems of crop nutrition and soil fertility is also conducted by the United States Department of Agriculture at the Agricultural Research Centre at Beltsville, Maryland, and at a number of Federal field stations in different parts of the country. Most of the field stations are tied closely to the work at Beltsville, and the programmes are worked out co-operatively with the state experiment stations and are a functional part of regional or national programmes.

In *Egypt* the Ministry of Agriculture, the Royal Agricultural Society, and the Nitrate Corporation of Chile are the agencies responsible for field experimentation. In *China* the National Agricultural Research Bureau of the Ministry of Agriculture and Forestry has conducted a nation-wide scheme of fertilizer experimentation with the co-operation of provincial agricultural bureaux, experimental stations, agricultural colleges, and other institutions.

In certain countries, such as *Denmark*, *Finland*, and *the Netherlands*, associations of farmers carry out field experiments in addition to the work done by state experiment stations.

Denmark's ten state experiment stations have made field tests of liquid and solid manure and chemical fertilizers since 1893. "Local" experiments on farms, so called to distinguish them from those carried out by the state, have totalled no less than 70,000 during the 50 years from 1896 to 1946. This kind of experimentation was initiated by government field-crop advisers among farmers with medium-sized holdings, and the state has continued to defray part of the expenses, though the experiments are now conducted by agricultural advisers engaged by farmers' societies (*De danske Landboforeninger*). Organizations of small-holders (*De danske Husmandsforeninger*) later joined in. Provincial farm organizations undertake field experiments on more general problems and compile reports from the local societies. These field trials are thoroughly planned and

carried out with a sufficient number of replications to guard against error; they are often supplemented by analysis and additional investigations, and the results are reliable. Taken together with the work of the experiment stations, facts gained from this great body of research form the basis upon which Danish extension work is carried out. More recently these annual experiments have to some extent been replaced by soil investigations, but "local" experiments remain the only way to measure the effect of fertilizer on farm land.

In the *United Kingdom*, field experiments are conducted by various research institutes supported by agricultural departments, the Agricultural Research Council, the National Agricultural Advisory Service, the universities, and certain industrial organizations.

It is not within the scope of this publication to describe the authorities in charge of field trials in every FAO member country. The examples cited, however, demonstrate that many satisfactory arrangements are possible to meet the conditions existing in different countries.

The methods adopted in different countries for advising the individual farmer on soil fertility and fertilization problems also differ widely. In all countries reporting in the FAO survey, some provision is made for personal advice to the farmer by trained agriculturists. Some countries also provide for advice by soil specialists and for analyses of soil samples from farmers' fields.

In *Czechoslovakia*, for instance, there is an obligatory scheme to determine fertilizer needs based on soil analysis. All farmers owning more than two hectares of land are required to participate. The soil sampling is done under expert supervision and the soil testing is carried out in nine state soil laboratories. The tests made are for lime, phosphate, and potassium requirements, it being assumed that all soils in Czechoslovakia are in need of nitrogen. Advice is given by district extension agents to the farmers on the basis of the soil tests. The cost of analysis is defrayed from small contributions paid by farmers, which vary with the size of the area investigated.

In *England* and *Wales*, inauguration of the National Agricultural Advisory Service in October 1946 put advisory work on a national basis. This service has provided a more even distribution of advisory facilities throughout the country, and has given farmers access without cost to a wider range of specialist advice. The service is organized on the basis of eight provinces, each in charge of a provincial director. At the provincial centre there is a team of specialists in different fields, including soils. In each county within a province there is a county headquarters under a county agricultural officer, a number of district officers, and county "subject" specialists. The district advisory

officer is in closest contact with the individual farmer. There are also county agricultural executive committees, representing a fund of local knowledge in each county, from which the staff of the National Agricultural Advisory Service obtains advice as to the most suitable lines on which to conduct local advisory work. The service functions in three ways: by giving advice when required; by disseminating information on the results of research; and by carrying out investigations. A farmer needing advice consults the district advisory officer, who may give the advice himself or may seek further guidance from soils specialists. Soil samples are normally taken by the district officer or by someone from the laboratory of the provincial centre. The farmer is supplied, not with the numerical results of the soil analysis, but with concrete recommendations based on the analysis. A similar service, also free of charge to the farmer, is provided by the three colleges of agriculture in *Scotland.*

In *Finland*, the agencies instructing farmers in the use of fertilizer and lime are the Central Committee for Experimental Activity (*Maatalous Koetoimintalliito Keskusliitto*), subordinate to the Ministry of Agriculture (*Maatalousministerio*); the Association for Field Experiments (*Koetoimintalliitto*); agricultural companies; and the State Sulphuric Acid and Superphosphate Mills (*Valtion Rikkihappo-ja Superfosfaatti tehtaat*), charged with the import and sale of fertilizers.

In *France*, each *département* (county) has a director of agricultural services (*le Director des Services Agricoles*) with a technically trained staff capable of advising farmers on soil fertility problems. Soil analyses are made and interpreted by the Institute of Agricultural Research at Versailles (*Institut des Recherches Agronomiques*) and its five regional laboratories and by county laboratories which receive grants from the Institute. Some of this work is also done in the laboratories of state and Catholic agricultural colleges. Published instructions for taking soil samples are available, and farmers are requested to give information on soil conditions, cropping, and fertilization. The request for analysis generally rests on the initiative of the farmer, though it might be stimulated by the advice of the county agricultural agent. A nominal fee is generally charged for analyses and interpretations. Advice to farmers is also given by private organizations, of which the most important are commercial companies, the fertilizer trade, and some co-operatives sponsored by national or local farmers' organizations. These private organizations also analyse soil samples.

In *Ireland*, 68 agricultural instructors are employed by committees of agriculture, which are statutory bodies deriving their finances

partly from the state and partly from rates (local taxes). These instructors advise farmers on all their problems, including soil fertility and fertilizers, and conduct experiments and demonstrations on numerous farms throughout their districts. They also take soil samples where necessary and transmit them to the Department of Agriculture for analysis. The samples are analysed free of charge at one of the five agricultural colleges under the control of the department. In special areas where soils are poor and holdings small, the work of the agricultural instructors is supplemented by that of agricultural overseers and their assistants, who are employed by the Department of Agriculture.

In the *Netherlands*, farmers and horticulturists are advised on soil fertility problems by consultants of the Agricultural Extension Service (*Rijkslandbouwvoorlichtingsdienst*). Farmers take their own soil samples and submit them to a laboratory operated by the Combined Farmers Association (*Landbouworganisaties*). The horticulturists have their soil samples analysed by specialized experimental stations operated co-operatively by the Horticultural Associations (*Tuinbouworganisaties*) and the State. Both farmers and horticulturists pay for their analyses.

In *Norway*, farmers can obtain advice from county agents specializing in soils and crops, from agricultural advisers working with smallholders, and from the agricultural college and schools. The soil laboratory at the agricultural college and two state laboratories make analyses of soil samples for farmers, but the number of these samples investigated per year has not been very large.

In *Switzerland*, institutions concerned with the analysis of agricultural materials provide advisory services to farmers on soil fertility problems and fertilizers. For a small price these institutions analyse soil samples and indicate what fertilizers are needed. A great number of such samples are analysed annually. The agricultural colleges also give advice on this subject, and so do the individual professors of agriculture. The farmers can also increase their knowledge by reading agricultural journals and scientific bulletins. The agricultural institutions publish, among other matter, articles dealing with the use of fertilizer and manure, and fertilizer manufacturers have established a type of advisory service through their trade journals.

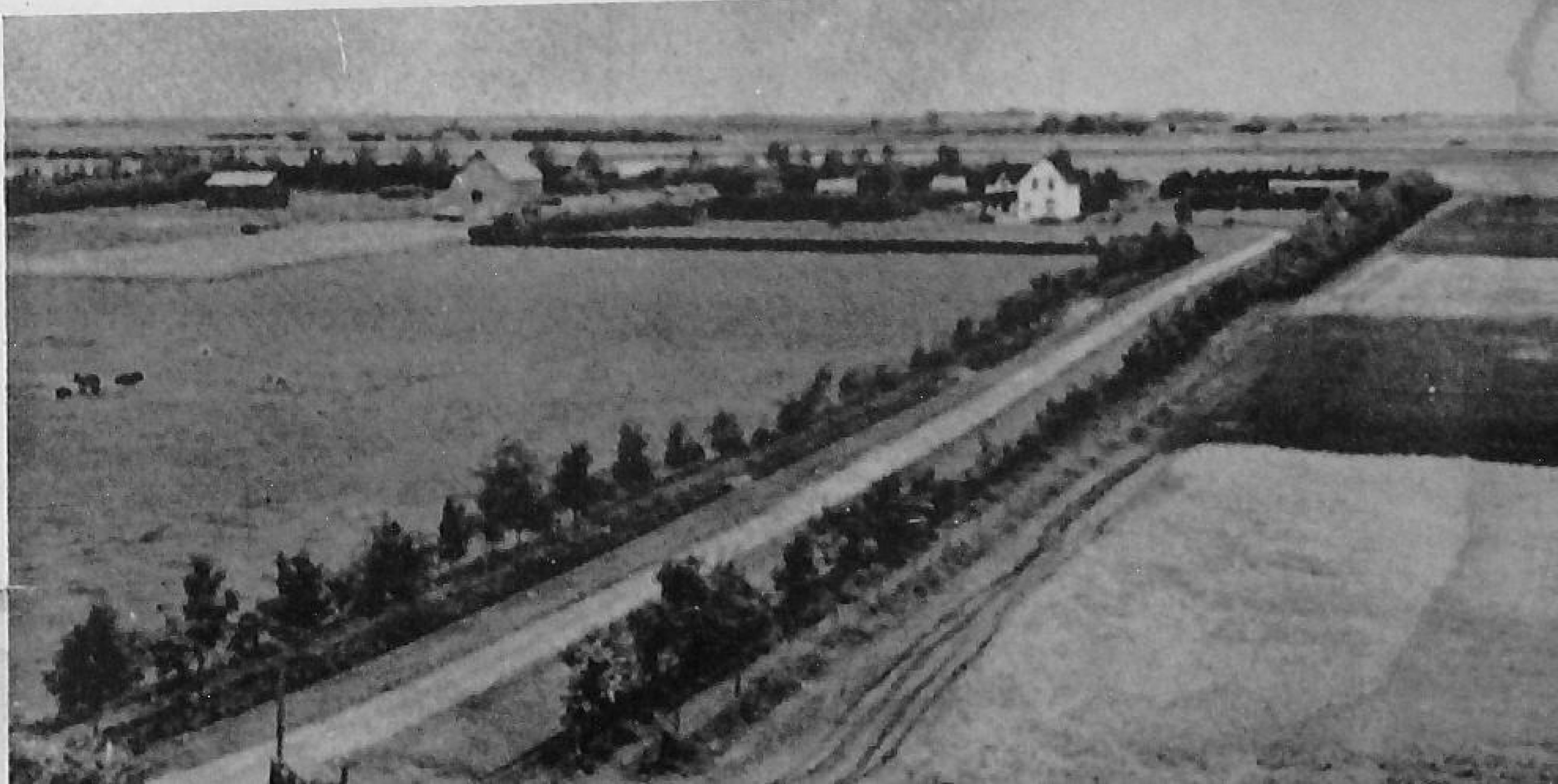
In *Chile* the technical personnel of the provinces and of the Agricultural Extension Division (*Departamento de Extensión* (*Agrícola*) of the Bureau of Agriculture (*Dirección General de Agricultura*) are primarily responsible for advisory services to farmers. These technicians are provided with soil-testing equipment which permits them to make many of their recommendations on the spot. However, when

Photo No. 48. A view of Broadbalk Field, the oldest experimental field in the world, at Rothamsted Experimental Station, Harpenden (Herts), England. This land has been cropped under experimental control for 106 years. In the immediate foreground and in the far background, the plots at the right of the central strip have had manure, whereas those on the left have had no manure or commercial fertilizer. The intervening area is fallowed in order to control weeds. (15 July 1947.)

Photo by Charles E. Kellogg.

Photo No. 49. A demonstration farm or Illustration Station, as it is called in Canada, at Lyleton, Manitoba. This farm is typical of thousands in Canada. The farmer himself operates it with his own resources and initiative, but follows technical advice and uses the best methods recommended. On the advice of agricultural technicians the windbreak has been planted and rotation is practised on the right.

Photo by courtesy of the Central Experimental Farm, Ottawa, Canada.



more complex problems arise, technicians or farmers can send soil samples for analysis to the Agricultural Chemistry Division (*Departamento de Química Agrícola*) of the Bureau of Agriculture (*Dirección General de Agricultura*). Results of the analyses, with suitable recommendations for fertilizer application, are given by the laboratory. In addition to this governmental advisory work, public and private organizations such as the Agricultural Colonization Fund (*Caja de Colonización Agrícola*), the National Agricultural Society (*Sociedad Nacional de Agricultura*), and all the chief fertilizer companies are developing activities in this field.

In *Peru* three agencies advise farmers on soil fertility and fertilizer problems. These are the Division of Soils and Fertilizers of the Bureau of Agriculture (*División de Suelos y Abonos de la Dirección de Agricultura*), the National Centre for Agricultural Investigations and Experimentation at La Molina (*Centro Nacional de Investigaciones y Experimentación Agrícola de La Molina*), and the Guano Administration Company (*Compañía Administradora del Guano*).

In the *United States*, agricultural extension activities have been vigorously developed since the turn of the century. In the individual states these activities are headed by the Director of Extension, who is a staff member of the agricultural college and operates in conjunction with the Federal Extension Office in the United States Department of Agriculture. Subject-matter specialists, such as agronomists, soil specialists, and entomologists, who are also staff members of the college, help the farmer personally at farmers' meetings or through one of the 3,000 county agriculture agents. Extension specialists and agents are employed jointly by the Federal Government and the state governments through the agricultural colleges. The county extension agents are jointly employed by the county governing bodies. These agents carry on educational and demonstration work on all problems the farmer faces, including soils and fertilizers. They are not responsible for regulatory activities of the government. Soil specialists of the extension staff in each state carry to the farmers, either directly or through county agents, the latest findings of research in soil fertilization and management. Radio and the press are extensively used. In many areas extension agencies conduct one- or two-year field demonstrations of fertilizer needs by means of sample plot layouts on farm fields.

Soil samples may be obtained by the county agent or by a representative of the soils laboratory, but usually the sample is taken by the farmer himself, following detailed directions on sampling procedure and preparation furnished by the soil-testing laboratory. Soil testing is free in many states, while in others there is a nominal charge. With

the soil samples the farmer also transmits to the laboratory, on a prepared form, a history of the fertilization, management, and cropping practices of the fields being sampled. The results of the analyses are sent to the farmer by the appropriate extension specialist, with specific recommendations and often a discussion of these recommendations in terms of the analyses and the previous management history of the field. In recent years a considerable number of commercial soil-testing laboratories have also been established in truck-farm and orchard areas where special and urgent soil problems arise.

In the *Netherlands East Indies* the experimental stations for sugar cane, coffee, tea, hevea, tobacco, etc., organized by the Plantation Associations for such crops, have conducted a great deal of research and advisory work on soil fertility problems for their members. All the costs have been defrayed by the plantation companies. The Central Agricultural Research Institute of Buitenzorg, devoted to the native agriculture, has also done much analytical work in connection with such action programmes as irrigation and colonization. In all parts of the Archipelago the peasants have been able to obtain the advice of the Agricultural Extension Service. Such advice has been based chiefly on the results of experimental fields and to some extent on soil analysis.

These examples indicate the different methods used to help the farmer with his particular problems. From the reports of countries it is evident that the use of private farms as pilot research farms is not the normal practice in most countries. On the other hand, field demonstrations on private farms, demonstration farms, or illustration stations are used in a number of countries to spread knowledge and encourage the use of better practices.

In most countries where chemical and commercial fertilizers are used, provision is made to protect farmers against fraudulent fertilizer specifications.

ECONOMIC ASSISTANCE

The extent to which a farmer can use purchased fertilizers and soil amendments depends on his financial resources and on the price relationship of these materials to his produce. Even if he has all the necessary technical knowledge, his economic position is likely to have the strongest influence.

Subsidies. A number of countries use subsidies for fertilizer and lime to maintain a favourable balance between the price of these materials and agricultural prices. These subsidies take various forms. The fertilizer trade may receive a bonus from the government when

fertilizers and lime are sold to the farmers at a certain price. There may be a subsidy on freight rates. Farmers may pay the full price charged by an unsubsidized and uncontrolled industry and then be reimbursed by the government.

In *Australia*, superphosphate is sold at a fixed price, based on cost of manufacture, and a subsidy is also paid directly to cash consumers purchasing one ton or more. This subsidy covers the superphosphate used in mixed fertilizers. A subsidy of £3-£4 per ton is also paid to farmers for nitrogenous fertilizers. One state pays a direct freight subsidy on superphosphate carried on the state railway system. The other government-owned railway systems carry superphosphate at exceptionally low rates, below the actual cost of haulage.

In *New Zealand* the transportation of agricultural lime, which has to meet certain quality specifications, is subsidized.

To encourage the use of chemical fertilizers, particularly nitrogen for use primarily on food crops, the Government of *India* has undertaken a plan known as the Central Fertilizers Pool. The price of the imported nitrogen materials and that of locally available supplies is averaged, and allocations made to provincial governments are charged at that price. The provincial governments that actually undertake the distribution of these fertilizers to farmers charge a price usually half of the price mentioned above. The difference, which is the net subsidy on the distribution of chemical fertilizers, is shared between the Central and Provincial Governments in most cases on a 50-50 basis. Moreover, the Central Government assists in the transportation of imported fertilizers from the ports to the centres of distribution by giving these consignments a very high priority.

In the *Union of South Africa* the fertilizer prices are controlled by the government, which pays £1 per ton to the seller producing evidence of sale to a farmer. An indirect subsidy on fertilizer, lime, and manure has been in operation since 1937 involving a rebate to the farmer of 75 per cent of the railway transport charge. Special schemes to encourage the production of certain types of crops—e.g., wheat, lucerne, and groundnuts—are recommended from time to time by the Department of Agriculture; if approved by the government, assistance is given to participating farmers in the form of loans or rebates on the cost of seed and fertilizers. Similarly, the Ministry of Agriculture (*Ministerio de Agricultura*) of *El Salvador*, which has been interested in maize production, furnishes farmers chemical fertilizers at cost price.

To develop the production of agricultural lime for soil amendment, and its transportation from quarries to farms, the Dominion Government of *Canada* subsidizes the provinces to the extent of 50 per cent

of the amount paid out by the provinces. The agricultural lime programme of each participating province is subject to approval by the Dominion Government. The provinces pay production subsidies on machinery replacement, the development of new quarries, and part or the whole of transportation charges from the quarry. In return, the producer has to sell the lime at a price f.o.b. quarry pre-arranged between him and the provincial government.

In the *United States*, under the Soil Conservation and Domestic Allotment Act, the Federal Government pays roughly half the cost of phosphate fertilizer and lime delivered at the farm when these materials are used on soil-building crops like grasses, alfalfa, and clover. No assistance is given if these materials are used on row crops such as cotton, wheat, and maize.

The Act is administered through state and local farmer-elected committees under the direction of the Production and Marketing Administration, United States Department of Agriculture. The general aim of this programme is to help the farmers to put soil-conservation practices into effect. Once the practices are established, the farmers are expected to keep them up at their own expense. Some 26 million metric tons of lime and 2·5 million tons of phosphate fertilizers (on the basis of 20 per cent P_2O_5 content) were applied in the United States in 1947 under this arrangement.

In *Norway*, nitrogen is sold under government control by Norsk Hydro at the 1938-39 price. The sale of potash and superphosphate is subsidized, and prices of these commodities to the farmer are held to 10 per cent and 70 to 80 per cent respectively above pre-war levels. The same price relationship applies to mixed fertilizers.

In the *United Kingdom*, subsidies keep fertilizer prices at the 1940 level at the fertilizer plants. There is no provision, however, for keeping the cost of transportation from the plant to the farmer at this level. The following procedure is used to stabilize prices: When a government agency buys raw material in bulk, as in the case of phosphate rock, it imports and then issues the material to the manufacturer at the 1940 price. When the producer buys certain materials, e.g. sulphuric acid, the agency refunds to him the cost above the 1940 level, thus keeping all his raw material costs at 1940 prices. The manufacturer is further reimbursed for increased costs of production and distribution over the 1940 level. The selling price of fertilizers is controlled by statutory rules and orders which fix prices for fertilizers delivered to the nearest railway station, except for muriate and sulphate of potash, which are quoted at importers' stores. Since 1937 one-half the cost of approved liming materials delivered at the farm has been paid by state subsidy, and quite recently the subsidy has

been extended to cover one-half of the cost of spreading liming materials on the land.

Credit. These examples show how countries, by means of subsidies, can give economic assistance to encourage the use of fertilizers. But in some countries the financial resources of farmers are so low that they cannot raise enough cash at planting time even to pay for subsidized fertilizers. Under such conditions credit should be made available until the next harvest at very low rates of interest. The cost of the fertilizer can then be met from the value of the added production.

In *China*, for example, the Farmers' Bank supervised the distribution of fertilizers on the mainland, administered the government policy of agricultural loans, and within this policy sold chemical fertilizers on credit to farmers. The government agreement with the Farmers' Bank provided for the sale of approximately two-thirds of the fertilizer to areas where relief was not so vitally needed and for free distribution of the remainder to farmers in urgent need. Funds received from the sales were used to finance the handling and transportation of all the fertilizers on the mainland, but the price paid by the farmers did not cover the initial cost of the fertilizers.

In *New Zealand*, credit for the purchase of fertilizers and lime is provided chiefly by private organizations such as co-operative dairy companies, trading banks, and stock and station agents. Although the State Advances Corporation and the state-owned Bank of New Zealand are concerned more with long-term mortgage loans and with advancing money for general agricultural development and improvement, they do give credit for the purchase of fertilizers and lime, usually as part of a general improvement programme.

THE aim of raising crops is to feed and clothe mankind. Although continuing research is needed to gain ever better control of the physical and biological factors important to crop production, the great advances in science up to now have provided the means to protect crops and to increase their yields. If full use is made of present scientific knowledge and technology for crop production in all parts of the world, great advances can be made towards building healthful lives and providing adequate diets for all. One of the strongest links in the chain of successful crop production is the efficient use of fertilizers. The farmer himself has to forge it, but he needs technical guidance and, under some conditions, economic assistance if this link is to be strongly made.

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CONVERTING FACTORS—GENERAL MEASURES

Measure	Common Metric Units with Customary British Imperial and United States Equivalents	Customary British Imperial and United States Units with Metric Equivalents
Area and Distance	1 hectare = 2·471 acres 1 metre = 1·0936 yards 1 metre = 39·37 inches	1 acre = 0·4047 hectares 1 yard = 0·9144 metres 1 foot = 0·3048 ,,
Weight	1 kilogramme = 2·2046 pounds 1 metric ton = 2204·6 pounds 1 metric ton = 1·1023 short tons 1 metric ton = 0·9842 long tons	1 pound = 0·4536 kilogrammes 1 short ton = 0·9072 metric tons 1 long ton = 1·0161 ,, ,,
Capacity	1 litre = 0·0275 bushels (Br.) 0·0284 ,, (U.S.) 1 litre = 0.2200 gallons (Br.) 0·2642 ,, (U.S.) 1 litre = 0·8800 quarts (Br.) 1·0566 ,, (U.S.)	1 bushel = 36·28 litres (Br.) 35·24 ,, (U.S.) 1 gallon = 4·5461 litres (Br.) 3·7853 ,, (U.S.) 1 quart = 1·1365 litres (Br.) 0·9463 ,, (U.S.)

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